INTRODUCTION

In the last decade, proton isolated VCSELs have become the industry standard for short wavelength (850nm) gigabit data communications links on multimode fiber. As the speeds have increased beyond 2Gbps, however, the oxide isolated VCSEL is increasingly the preferred source. While proton isolated VCSELs can serve this application, oxide isolated VCSELs have proven easier to drive at the higher speeds. Many characteristics are independent of the isolation technology, so the reader is referred to the Finisar VCSEL website at www.Finisar.com/vcsel for general information on VCSEL characteristics. The present note augments that more general information with specifics related to driving oxide isolated VCSELs at high bit rates. Generally, this information relates to TO-can packaged and connectorized VCSELs operating at speeds up to approximately three gigabits per second. A separate application note deals with operation at even higher speeds [1].

Oxide VCSEL Equivalent Circuit Model

Packaging of VCSELs and monitor photodiodes requires attention to details in order to deal with electrical parasitics. These parasitics, small as they may be, can dominate the performance through their interaction with the laser-driver interface. For this reason, the most important design consideration in building an optical transceiver is often the electrical interface to the VCSEL package. This interface is not just the driver chip, but includes as important elements the details of the board layout, parasitic capacitance or inductance of any passive elements incorporated in the drive path, and the length of lead from the VCSEL package to the solder joint on the board. It is not always intuitive how each of these elements affects the VCSEL performance. Subtle changes to packaging can result in dramatic performance changes in optical characteristics; a fact that was used to good effect in many proton VCSEL based designs.
Many commercial laser drivers are available that interface to Finisar oxide isolated VCSELs. Each of these laser drivers may require a different interface circuit or set of VCSEL driving conditions. It is considered outside the scope of this application note to address designs with specific laser driver manufacturers, though many of them offer design assistance using Finisar VCSELs. This application note instead provides general guidance and characterization information for the Finisar product. The electrical equivalent circuits described below were derived from S parameter measurements of VCSELs in TO-style packages, and are intended to be a starting point for modeling performance. The values are shown for above-threshold operation at room temperature; some characteristics may change due to temperature and driving conditions. The reader is referred to the application notes VCSEL Spice Model [2], Modulating VCSELs [3], and the product data sheets [4] which are available on the Finisar VCSEL website for more detailed information on variations of VCSEL characteristics with temperature. Like all models, the ones detailed below are representative, but do provide useful design guidelines. The models are intended to characterize the electrical interface to the VCSEL, so no attempt is made to model the optical output. Two models are given, the Common Anode (HFE4x90-xxx), and Common Cathode (HFE4x91-xxx) configurations. While these two configurations represent the bulk of Finisar production, other configurations are possible. The parametric values shown in the models are typical. Most do not vary much from device to device, with the exception of the package lead inductances, which are dependent on the user-chosen lead lengths, and the parasitic capacitances from the monitor photodiode to the VCSEL cathode and to the package header. In different designs these latter values can vary substantially, but within any given design they are nearly constant. In the standard configurations, the VCSEL and PD common lead is common to the case of the TO package.
However, other configurations are possible, and it is left to the designer to decide the best interface to the chosen laser driver and detail layout of the printed circuit board.

In other possible configurations, the details of the parasitics are modified. The most common additional parasitics can be modeled as a small (1-2pF) capacitance between the VCSEL Cathode and PD Cathode, and a small (1-2pF) capacitance between the VCSEL Cathode and the TO header case lead. Please contact Finisar for design support for models outside of the standard configurations.

The terminology of “common anode” and “common cathode” sometimes results in confusion for the user. Here, we use these terms to refer to the commonality of the laser terminal (anode or cathode) to the photodiode terminal. The use of the word “common” does not imply that this lead is connected to the case lead.

Making Beautiful Eye Diagrams

The most challenging aspect of building an optical transceiver is managing the trade-offs between the various ac characteristics, such as rise/fall time, jitter, overshoot, extinction ratio, etc., and other considerations such as reliability, eye-safety, margin, and the like. With proton VCSELs, it was occasionally necessary to hand tune each VCSEL with a peaking circuit to effectively trade off the various characteristics, especially at very high data rates. While a peaking circuit is not necessary to operate Finisar oxide VCSELs, there are still trade-offs in ac performance. Before discussing these trade-offs in detail, it is beneficial to digress for a moment into VCSEL design details.

Generally speaking, for a fixed threshold current density ($J_{TH}$), the speed of a laser is proportional to the square root of the current density ($J$) above that threshold, i.e.

$$Speed \propto \sqrt{J - J_{TH}}$$

[5]. This would clearly indicate that better speed performance would be achieved with higher operation currents. However, the long-term reliability of VCSELs depends inversely on the square of the total current density,

$$Reliability \propto \frac{1}{J^2}$$

which means that the reliability of the device decreases rapidly with increased current. Hence a balancing act must be performed between reliability and acceptable performance. One way to increase current density, and therefore speed, is to decrease the size of the VCSEL active region for a fixed current [5]. However, Finisar has shown that for any basic VCSEL design there is a relatively strong dependence of reliability on the aperture size, and smaller is worse [6]. Finisar has made a conscious decision to provide the highest reliability VCSELs, even if at the potential expense of some cosmetic ac performance characteristics. (“Cosmetic” is beyond functional, resulting in beauty points, but no sensible improvement in link performance, reliability, or standards
compliance. Of course some margin to specifications is desirable to provide confidence that performance will be robust over temperature and life and is therefore necessarily, a forced trade-off decision. But beyond that point, tangible deficits in reliability and cost trade off against negligible benefits in performance. In an exaggerated example, a 75-ps rise time may be better than a 135-ps rise time, but a 1-ps-rise time is not better than a 75-ps one.) One should expect excellent ac performance from Finisar VCSELs, and be comfortable that reliability integrity of the device has not been compromised to achieve this.

The most common modulation trade-offs are between optical power, extinction ratio, overshoot, and jitter. Both Data and Telecommunications standards require that all laser sources emit below a specified eye safe power. Optical receivers also desire a large difference in power between an optical “1” and an optical “0” to optimize bit error rate performance, and power penalty errors are added to the link as the power ratio between a “1” and “0”, or extinction ratio, is decreased. In addition, a higher extinction ratio has been traditionally desired to facilitate field measurements. However, maintaining a high extinction ratio in a directly modulated laser generally means sacrificing jitter performance and overshoot performance. Jitter in a digitally modulated laser refers to the statistical distribution in time of the rising and falling edges of the optical signal at the logical crossing point (average power level) measured as a peak-to-peak or RMS deviation. The total jitter is the sum of two components, one a stochastic random process, and the other a deterministic process. Random Jitter (RJ) is a function of the average power of the VCSEL: the more power, the lower the random jitter. Deterministic Jitter (DJ) is a strong function of the extinction ratio: the higher the extinction ratio, the higher the jitter. This is primarily due to the changes in the turn on dynamics of the laser as the optical “0” state gets closer to the laser threshold. The Total Jitter (TJ) is generally described as the sum of the DJ and 14×RJ. Accurately measuring TJ can be a tricky proposition generally requiring measurement of the Bit Error Rate (BER) as a function of the clock offset, commonly referred to as a “Bathtub Curve.” The accuracy of the measurement is critically dependent upon the test methodology employed and the optical and electrical components used in the measurement, including connectors, splices, bias T’s etc. The user is referred to the various optical standards for a tutorial on the techniques.

Overshoot in a VCSEL can come from a variety of sources, including mode selective optical coupling effects, spatial hole burning, external circuit component parasitics, etc., and most critically, the relaxation oscillation. Overshoot is also commonly observed as the Relaxation Oscillation Frequency (ROF) and is present in all lasers. In VCSELs, the ROF is nearly critically damped, and generally there are only one or two cycles evident in the data patterns. As discussed previously, the ROF and damping thereof is proportional to the square root of the stimulated current density above threshold [5], one way to remove or reduce their effects is to apply more current to the VCSEL (with the consequent increase in average power). This moves the ROF outside the maximum bandwidth of the system, and also increases the damping. In Finisar oxide VCSELs, ROFs range from 3 to 8 GHz, depending on the current density. The second major effect that can lead to overshoot in VCSELs is the mode evolution that occurs at the beginning of each turn-on transition. In a typical oxide isolated VCSEL, the laser first turns on in a fundamental mode which is Gaussian-like and
centered in the cavity. The fundamental mode generally has a very low divergence, and couples very well to the multimode optical fiber. As the carriers redistribute into a quasi-equilibrium condition, the lasing rapidly evolves into higher mode orders, which are generally characterized by a higher divergence. The mode evolution typically happens in a hundred picoseconds or so. This coupling effect can often be readily observed by intentionally defocusing the fiber tip from the image plane of the lensing system. Lowering the extinction ratio can also control the amount of overshoot due to modal evolution by keeping the VCSEL in the higher order modes at all times. The user is in a box, trying to balance the extinction ratio, over-shoot, jitter and power to find a “sweet spot” of laser operation that simultaneously satisfies the competing requirements. (An important point in this discussion is that the amount of overshoot observed in both amplitude and time is critically dependent upon the bandwidth of the measuring system. High bandwidth measuring systems may reveal turn on transients and artifacts that will not have any system level effects because of the finite receiver bandwidth. It is recommended that the user implement appropriate bandwidth limitations in the measurement system as recommended by the various optical standards. Measurement of rise and fall times are also affected by the choice of measurement bandwidth, and the user is once again referred to the various optical standards for appropriate bandwidth requirements.) No VCSEL is exempt from the requirement to perform the trade-offs described above, and every VCSEL can show substantially better performance and robustness to temperature changes when the trade-off is done properly. As an example, see the eye diagrams in the figure below, which demonstrate that even a less-than-perfect VCSEL can show acceptable performance when set up appropriately. These eye diagrams clearly demonstrate the effects of the trade-offs between jitter, overshoot, extinction ratio, and average optical power. Also summarized below is the measured ROF and overshoot as a function of the extinction ratio, which also demonstrates the benefits of lowering the overall extinction ratio. The data presented is for a fixed optical power of –6dBm.

The eye diagrams and data are from unfiltered eyes from a non-typical VCSEL to more clearly show the effects of average optical power and extinction ratio on overshoot and the relaxation oscillation frequency. In general, Finisar recommends maintaining a modest extinction ratio (~10 dB or lower, depending on the application standard, and best set using a K28.7 pattern) and average optical power of ~4.5 dBm.
While some Finisar VCSELs produce wide-open eyes even at unreasonably high extinction ratios and low powers, all benefit from operation near the optimum settings described above. Please note, as will be described further in the next section, that the most beautiful eyes at room temperature are not necessarily the most robust over temperature changes.

The Figure below demonstrates a typical VCSEL operating at power levels of –4.5dBm and –6.5dBm, and extinction ratios of 8, 10 and 12dB. The VCSEL was modulated at 2.5Gbps and a double speed Ethernet mask (40% margin incorporated) was used with a 3.125GB Bessel Thomson filter to measure the optical eye diagrams. As is evident from these pictures, the general performance trade offs of improved eye performance for jitter, overshoot, and rise/fall times with power and extinction ratio must be carefully considered when design an optical transceiver.

Finally, TO can packaged VCSELs can be made to run at a wide range of speeds as indicated in the figure above where a single VCSEL is demonstrating double and quadruple speed fiber channel, double speed Ethernet, and XAUI interface speeds. However, operation at 10Gbps is limited due to the parasitics of the TO package, and is not recommended with these devices. In this example the average power was set to –4.5dBm, with an extinction ratio of 10dB. Appropriate filtering was used for each eye except for the 4x Fibre channel measurement, where the XAUI filter was used.
Operation Over Temperature

One of the most important reasons to avoid excessively high extinction ratios is that no temperature compensation circuit or feedback control is perfect, and if the extinction ratio increases at higher or lower temperatures unacceptable jitter could result. In general, Finisar recommends using an Average Power Control (APC) circuit when operating VCSELs over temperature. Typically, the APC circuit works by adjusting the average current through the VCSEL to maintain a fixed amount of
current in an optical power monitoring photodiode located inside the VCSEL assembly. However, it is not sufficient to simply adjust the average current and expect to maintain good optical performance over the entire operating range. It is generally necessary to also adjust the amount of modulation current applied to the VCSEL as well, usually through a circuit-programmed temperature coefficient. Why this is important is illustrated in the following graphs showing typical performance of a Finisar oxide VCSEL over temperature. Please note that this is only typical performance, refer to the Finisar VCSEL data sheets [4] for the possible range of parametric performance.

Figure A is a plot of the VCSEL voltage and B is a plot of the light output as a function of current, for temperatures ranging from –40 to +120°C. Figure C is a plot of the threshold current (red line), slope efficiency (black line) and series resistance (blue line) as a function of temperature, normalized to the 20°C values. Also shown in C is the current, I_{MOD} (green line), above threshold at which the VCSEL achieves a fixed optical power. (The square root of I_{MOD} is the predictor of ROF described earlier. The same analysis can be done at a different fixed optical power, changing only the I_{MOD} curve and the predicted temperature changes in ER.) Figure D is a plot of how the extinction ratio changes with temperature, assuming a particular average power has been set by the dc current and the modulation current has any of the several fixed temperature coefficients shown in the legend. Please note that in the above VCSEL analysis, the actual change of slope with temperature was about –0.38%/°C. The nominal room temperature ER was chosen to be 10dB in this example, and the average power was set to 350μW (-4.5dBm). The choice of a different fixed power would result in a different set of curves, potentially with even greater extinction ratio changes.

Figures E and F demonstrate the effect on extinction ratio over temperature when lower (6dB) and higher (14dB) room temperature ER selected respectively. As can be seen in the figures E and F, choosing a lower extinction ratio set point is more forgiving to operation over temperature than a high extinction ratio. While it is impractical to hand tune the temperature compensation for each VCSEL, some general comments can be made. Lower temperature compensation will reduce the ER at higher temperatures, and over compensation of the temperature dependence will decrease the ER at lower temperatures.

The above analysis is based on the use of a current source laser driver makes the change of resistance with temperature (dR/dT) irrelevant.

When using a voltage driver with a VCSEL, the changes in resistance with temperature must be accounted for in a manner similar to that described above for the slope efficiency (I_{MOD}). dR/dT is typically –0.3%/°C.
Summary

The table above summarizes Finisar recommendations for optimal performance of oxide VCSELs in data communications transceiver design. Please note that this is intended as a baseline only, and Finisar makes no guarantees about performance in specific implementations.

References


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.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Performance Trend</th>
<th>Recommendation</th>
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<tbody>
<tr>
<td>Fiber Coupled Power</td>
<td>Higher is better</td>
<td>350μW (-4.5dBm)</td>
</tr>
<tr>
<td>Extinction Ratio</td>
<td>Lower is better</td>
<td>10dB, set with K28.7 pattern</td>
</tr>
<tr>
<td>I_AOD Tempco</td>
<td>Depends on application</td>
<td>-0.3%/°C *</td>
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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.

1. 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, chipscale packages, etc.
- Custom packaging options

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