Introduction

With the advent of the IEEE 10Gbps Ethernet [1] and the ANSI X3.T11 10GFC (Fibre Channel) [2] standards, optical interconnections at serial data rates of 10Gbps are becoming more prominent in data communications networks. In addition, suppliers of these new network centric links have formed several industry groups to standardize on the mechanical and electrical interface, e.g. XENPAK, XPAK, X2, XFP [3], among others. This application note is intended to aid the design engineer in using AOC’s 10GB VCSEL (HFE6x90) and detector (HFD6x80 – 850nm, HFD6x40 – 1250-1600nm) solutions for these emerging applications. For the latest in datasheet specifications, visit http://www.finisar.com/aoc.php.

Operation of lasers and detectors at 10Gbps requires a new approach to many aspects of the design of the laser packaging and ultimately transceiver packaging. AOC has designed a new TO can package while maintaining excellent mechanical, optical, and thermal characteristics at a competitive cost. The decision to maintain a TO can based infrastructure allows for a lower total cost by leveraging the significant manufacturing infrastructure.

Mechanical Interface for TOSA and ROSA

The AOC TOSA and ROSA assemblies consist of a TO-46 component aligned to an integral lens barrel. Connection to the next assembly is made through a flexible circuit, which gives great adaptability to a customer’s housing and PCB configuration. The features of the flexible circuit which allow this adaptability also make it vulnerable to damage during the assembly process. With care in handling the flexible circuit during assembly and careful control of the soldering temperature, successful assembly can be achieved with each device. The information contained in this application note describes the structure of the flexible circuit and lists the precautions and the process followed by the AOC for this type of assembly.
The flexible circuit used in the AOC OSAs (Optical Sub Assemblies) is designed to be thin and thus very flexible. The core is a .002” thick polyimide layer manufactured by DuPont [4]. This is clad on either side with ¼ oz copper. One copper layer is used for the signal traces and the other is used as a ground plane. Over each copper layer is a .001” thick cover layer, also made by DuPont. Total thickness of the flexible circuit is < .005”.

[Diagram of flexible circuit layers]

At the component end of the flexible circuit are copper pads which are attached to the TO-46 component leads. At the interconnect end of the flexible circuit are copper pads which are attached to pads on the customer’s PCB.

Since the solder pads of the flexible circuit are thicker, stiffer, and sometimes wider than the traces, the connection between the two is a weak area in the physical structure of the circuitry. For this reason the traces have been widened (and thus strengthened) by “tear-dropping” (or expanding) them as they approach the solder pads.

[Diagram of tear-dropped connection]

This also reduces the discontinuity seen by the high speed signals as they approach these solder pads. The openings, which are cut in the cover layer, serve as windows to allow the solder operation to take place.

[Diagram of plated thru hole and cover layer window]
By removing the cover layer material that would normally strengthen this copper connection, the traces are more susceptible to breakage in this weak area if the device is not handled correctly. In the area of the flexible circuit where the copper trace is protected by the cover layer, the flexible circuit can be bent once or twice to a radius as small as .015 without damage. Larger radii are preferred, both from a physical integrity and a signal integrity standpoint. However, when the flexible circuit is bent in the area of the trace exposed in a cover layer window, the results can often be a broken signal trace or a broken connection to the ground plane. Careful handling is the best means of protecting the integrity of these traces.

The amount and duration of heat used when soldering the flexible circuit to the PCB is another area of concern. AOC VCSEL Product Group operators have been very successful in soldering the flexible circuit using a soldering iron with a very small tip and controlling the temperature of this soldering tip to 800 °F. All flexible circuit assembly uses lead-free Sn-Ag-Cu alloy solder with a melting point of 217 °C (423 °F). Since the surface of the copper has been tin plated, there is no need to pre-tin the flexible circuit pads before assembly. Pre-tinning the PCB pads and even heating the PCB during the solder operation may reduce the amount of time required for the soldering operation, but this step has not been found to be necessary. Soldering the flexible circuit to the header leads typically takes 1 - 2 seconds each. Soldering to the pads on test boards typically takes 2 - 3 seconds each. Please note that the flexible circuit has a damage threshold of 700 °F, so care should be taken with the tip of the soldering iron. Finally, the flex circuit passes the solder float test for 10 seconds minimum at 288 °C.

In summary, therefore, the guidelines followed by AOC when assembling the flexible circuit are as follows:

1. Keep bends away from the ends of the flexible circuit where the traces are exposed in the cover layer windows.
2. Don’t pull on the flexible circuit as if trying to peel it off the back of the component.
3. Don’t push on the PCB end of the flexible circuit when forming a bend or when installing the OSA into an assembly.
4. Carefully control and limit the soldering time and temperature to the minimum needed.
5. This is an ESD sensitive device, so proper ESD precautions should always be taken during every step of the assembly process.

Once soldering of the flexible circuit to the PCB is complete, there are two other areas of concern. One is the method of securing the flexible circuit to the PCB and the other is unsoldering it from the PCB.

The flexible circuit has two notches located at the interconnect end which can be used to align it to the PCB. There are several ways in which epoxy can be added to provide strain relief to this assembly.

1. Carefully insert epoxy between the flexible circuit and the PCB.

2. Apply an epoxy fillet between the edge of the PCB and the bottom of the flexible circuit.

3. Apply epoxy on top of the flexible circuit along its edges. Be careful not to place epoxy on top of the two high speed traces as this could affect their signal integrity.

Occasionally, a TOSA or ROSA must be unsoldered from a PCB in order to be used in a different product. The typical unsoldering process using solder braid or other solder removing tool applied one pad at a time has consistently damaged flexible circuits rendering them unusable. The preferred method at AOC is to add solder to all six pads and then heat them all at the same time. Pulling the flexible circuit parallel to the surface of the PCB will safely remove the flexible circuit from the PCB. The copper pads of the flexible circuit can then have excess solder removed in preparation for being assembled into another product.

The product provided by AOC is not intended to contain all the plug features necessary for it to be the front end of a module. Instead, features are present to allow it to be snugly held in an injection molded or die cast housing. This housing would most likely be of a clamshell type (two pieces) that would securely hold the AOC product in place as well as have the fiber cable interface features. This housing would also have mechanical features to rigidly fix it in the customer’s module housing.

**TOSA and ROSA Optical Interface**

AOC offers 10GB components with both an SC and LC optical interface in footprints that are compatible with all of the associated MSA agreements. The fiber ferrule sleeve receptacle is designed in compliance with TIA FOCIS 3 (EIA/TIA 604-3A), and TIA FOCIS 10 (EIA/TIA 604-10) for the SC and LC respectively. A mechanical stop for the fiber end face is provided in the package, and is referenced in the detail mechanical drawings on the datasheets. (Note: The fiber stop is also referred to as the optical reference plane) It is recommended that users refer to the TIA FOCIS standards for mechanical definition of the SC and LC latching mechanisms.

The 10GB TOSA is specifically designed to interface to multi-mode optical fiber. Based on the work of the TIA FO2.2 committee, and the adoption of the Restricted Modal Launch (RML) by the IEEE
802.3ae, AOC has designed the VCSEL and lens system to be compliant with the specifications. While ensuring the bandwidth of the enhanced multimode fiber by restricting the modal launch into the optical fiber, it has also been shown that similar launches can significantly improve the bandwidth rating of traditional multimode fiber [7]. The fiber modal profile (encircled flux) of two worst case TOSAs are shown in figure 1. The blue lines are measured encircled flux profiles as a function of radius, and the red boxes indicate the forbidden areas. The eye diagram was taken after 510m of 2000MHz/km fiber. For details on how to measure the encircled flux in the optical fiber from the VCSEL launch, the reader is referred to the TIA/EIA 455-203. While the launch conditioning is critical for performance on the enhanced bandwidth multimode optical fiber, it will also generally greatly increase the reach of lower grade optical fiber, and link lengths far exceeding the 10GB Ethernet standards may be observed in application.

![Figure 1]

TOSA and ROSA Electrical Interface

Traditional laser packages such as the Transistor Outline (TO) style packages have been used for lasers in data links operating up to 2.5Gbps, and continue to be the package of choice for those applications. However, it has long been recognized by the telecommunications industry that these packages suffer from significant electrical parasitics that make operation at higher data rates very difficult. The butterfly style package and silicon optical bench (SiOB) designs work well for edge emitting lasers, but are not easily adaptable to low cost VCSEL packaging, and more importantly, to packages with optical connectors instead of fiber pigtails. In addition, Butterfly style packages also do not lend themselves to the highly automated assembly required of low cost components, and are not easily edge mounted in a customer application. Recently, there has been a great deal of interest in making TO style cans with reduced electrical parasitics such that they are amenable to operation at 10Gbps. Our studies indicate that operation at 10Gbps is possible in some TO style packages in a well controlled manufacturing environment. Early 10Gbps designs at AOC focused on a hybrid microwave ceramic approach which yielded much better results than early TO samples. Since then, AOC has designed a TO based TOSA that has equal electro-optical performance, and fits the
embedded TO manufacturing infrastructure. The TO approach will help meet the cost requirements of the market, and allow for very quick volume ramp up capability. The TO package also uses a flexible circuit interface.

The ROSA solution is a similar TO can based design which has excellent electrical characteristics. The ROSA contains a fast photodiode, a transimpedance amplifier, and several passive components. The flexible circuit interface to the package was designed to allow the user to comply with any of the Multi-Source Agreements (MSAs) that dictate the transceiver electrical, mechanical, and optical interfaces.

To build an electrical interface model for the VCSEL, each of the parts are analyzed independently into lumped circuit elements as indicated in the figure 2 drawing below.

![Figure 2](image)

The first piece to be analyzed is the VCSEL chip itself. Measurement of the S11 parameter is perhaps the best way to characterize the electrical impedance of the VCSEL. S11 can also be used to extract a lumped circuit model for the VCSEL. While the validity of lumped circuits at these operational frequencies is questionable, they are nonetheless an excellent visual tool for the designing engineer. Figure 3 is a representation of the VCSEL equivalent circuit. The model includes the bond wire inductance to the VCSEL, but no other packaging related parasitics. The VCSEL equivalent circuit model depicted below is for a cathode driven device. Other configurations will have variances in the placement of wire bonds.

![Figure 3](image)
This model must be paired with the appropriate packaging parasitics for each of the configuration offered by AOC, the anode driven, cathode driven, and differentially driven TOSAs. The three driver connections are also depicted schematically in figure 3. The TO can is designed to have a 50 Ohm electrical feed-through eyelet. The feedthrough can be modeled as an LC equivalent circuit with characteristic impedance of \( Z = \sqrt{L/C} \), or more accurately as depicted below. Typical values for feed through inductance 250pH, and 100fF capacitance.

![Diagram of feedthrough](image)

The flex circuit must be included to get the total impedance analysis. AOC has two flex circuit designs, one for the differential driving case where the high speed signal lines are 25\( \Omega \), and one that can be used for either the anode or cathode driven case, where the signal lines are 50\( \Omega \). Typical S21 parameters of the 50\( \Omega \) flex interface are shown in figure 4.

![Graph of S21 parameters](image)

Finally, the packaging parasitics and the devices can be taken together, and actual devices measured for S parameter data. The magnitude of \( S_{11} \) and \( S_{12} \) for the cathode driven package configuration is shown in figure 5. (The anode driven package is similar) S parameters for the differentially driven package is more complicated, and not presented here.
While AOC offers three different packaging configurations for the VCSEL, it is left to the designer to decide which of the configurations best suits the application. Choice of configurations depends on the laser driver chosen, the board level parasitics, etc. The user is referred to various vendors for more information on flexible circuit board material, such as http://www.dupont.com/fcm.

The flex circuit used for the ROSA has the same characteristic impedance as the cathode/anode driven flex described above. The output of the TIA is source terminated with 50\(\Omega\) and must be capacitively coupled at the flex interface.

The receiver package requires the photodiode to be externally biased, which can be used to measure the average current into the photodiode. The current into pin 1 is a direct measure of the average optical power at the receiver, and can be monitored and scaled to provide a measure of the average incident power. This implementation was chosen instead of other implementations because it is a direct measure of the optical power, providing the lowest error in received signal strength indication. A schematic for doing this is shown in figure 6. The voltage drop across the 100\(\Omega\) resistor is negligible.
Introduction to Triple Trade Off Curves

Before discussing the triple trade off curves, it may be beneficial to describe the relationships between extinction ratio (ER), optical modulation amplitude (OMA) and average optical power (PAVE). Figure 7 provides a schematic of the optical signal with the relevant values identified. The equations given are valid for linear units, and not for values expressed in decibels. In addition, a graphical representation of the relationship between OMA and ER for various average powers is also provided.

\[
\begin{align*}
ER &= \frac{P_1}{P_0} \\
OMA &= P_1 - P_0 \\
PAVE &= \frac{P_1 + P_1 - P_0}{2} \\
OMA &= \frac{2PAVE (ER - 1)}{ER + 1} \\
ER &= \frac{2PAVE + OMA}{2PAVE - OMA}
\end{align*}
\]
Triple trade off curves represent a modern approach to specifying optical components for fiber optic links. The trade offs represented by these curves are optical power, wavelength, and RMS spectral width of the optical source. The trade offs are a result of modal dispersion in multimode optical fiber and chromatic dispersion of single mode optical fiber and noise sources in both the transmitter and receiver. To provide the lowest total cost transmitters, the standards community recognizes the trade offs that are present in the link budget calculations. The penalties associated with the laser spectral width are taken into account at the receiver in the form of power sensitivity, specifically in the specified minimum OMA of the laser source. The triple trade off curves provided in 10GBASE-SX are reproduced here for reference.
For a two level system ("1" and "0") with Gaussian noise characteristics, a signal to noise ratio of 14 is required to achieve a Bit Error Rate (BER) of 10^-12. Logically, the wider the optical spectrum used, the more dispersion and other noise sources will cause problems, making the penalties higher for larger spectral widths. Also, the magnitude of the dispersion is a function of the center wavelength. Taking these two together, a penalty can be calculated for a particular center wavelength and RMS spectral width of the source. The penalty is then translated to the amplitude differences between an optical "1" and an optical "0", which is the Optical Modulation Amplitude (OMA) specification. The center wavelength of the VCSEL is controlled by the epitaxial design, and can be held within a few nanometers, and tunes with temperature at a rate of 0.06nm/C, and at a rate of 0.15nm/mA with current. The optical power increases linearly with current. The RMS spectral width is a function of the optical power and device design. AOC has developed a VCSEL with excellent operational characteristics that consistently meets the RMS spectral width requirements, having spectral width <0.4nm. This is a non-trivial design issue because conventional wisdom would drive designers to reduce the active area diameter, however this also has the adverse effect of increasing the RMS spectral width. RMS spectral width is also difficult to measure accurately in a multi-transverse mode laser like a VCSEL where the mode spacing can be very small. The current methodology specified is adequate for multi-longitudinal mode lasers. AOC is currently working with the Telecommunications Industry Association (TIA) to define test methodologies appropriate for multitransverse mode laser sources. The current methodology (FOTP-127) utilizes a gaussian fit to the peaks of the optical spectrum, and works reasonably well as long as all of the peaks are resolved. Typical mode spacing in a multi longitudinal mode laser is about 0.3nm, readily resolved by most optical spectrum analyzers, while mode spacing can be extremely small, less than 0.05nm. Peaks more than 20dB lower in power from the maximum are discarded. The method being proposed by AOC will utilize the entire optical spectrum in the gaussian fitting approach, and will lead to much better correlation within the industry. The figure below shows an optical spectrum from a typical VCSEL (red line), and the gaussian fit using the FOTP method (green line) and the proposed fitting method (blue line). There is reasonable agreement in the methodologies here because all of the peaks are resolved, but the correlation is adversely effected by lack of peak resolution.

Because of the high launch power allowed in the standard, there is a need to be aware of the tradeoffs necessary to maintain eye safe operation over the entire operating lifetime and ambient temperature. In addition to the power launched into the optical fiber, the user must be cognizant of the power emitted from the open bore of the fiber receptacle (i.e. when there is not a fiber plugged into the transmitter receptacle.) The open bore power must also be considered for operation over temperature, and for operation with an average power control circuit. The design criteria that must be considered include the tracking error of the photodiode to the light output, the temperature range of operation, the coupling loss, extinction ratio, and the coupled optical power. AOC has developed a launch budget analysis to assist the user in this analysis. Table 1 summarizes the approach taken, assuming class 1 eye safety is desired.
Table 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Units</th>
<th>Value</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Temperature</td>
<td>𝑇_𝐿</td>
<td>°C</td>
<td>-40</td>
<td>-</td>
</tr>
<tr>
<td>High Temperature</td>
<td>𝑇_𝐻</td>
<td>°C</td>
<td>85</td>
<td>-</td>
</tr>
<tr>
<td>Maximum average open bore power*</td>
<td>𝑃_𝑂𝐵,𝑀𝐴𝑋</td>
<td>dBm</td>
<td>-1.238</td>
<td>𝑃_𝑂𝐵,𝑀𝐴𝑋 = 0.39(10^(0.002(λ−700)))</td>
</tr>
<tr>
<td>Coupling efficiency</td>
<td>𝜂_𝐶ＯＵＰ𝐿𝐼ＮＧ</td>
<td>dB</td>
<td>-1.5</td>
<td>-</td>
</tr>
<tr>
<td>Monitor diode Tracking error</td>
<td>Δ𝑇𝑅𝐴𝑁𝐾</td>
<td>dB</td>
<td>0.25</td>
<td>-</td>
</tr>
<tr>
<td>Coupled optical power</td>
<td>𝑃_𝐶ＯＵ𝑃𝐿𝐸Ｄ</td>
<td>-</td>
<td>-2.9</td>
<td>𝑃_𝑂𝐵,𝑀𝐴𝑋 + 𝜂_𝐶ＯＵＰ𝐿𝐼𝑁Ｇ + Δ𝑇𝑅𝐴𝑁𝐾</td>
</tr>
<tr>
<td>Extinction ratio</td>
<td>ER</td>
<td>dB</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>Coupled OMA</td>
<td>𝑃_𝑂𝑀𝐴</td>
<td>dBm</td>
<td>-2.72</td>
<td>See previous equations</td>
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<tr>
<td>Min coupled OMA</td>
<td>𝑃_𝑀𝐼𝑁,𝑂𝑀𝐴</td>
<td>dBm</td>
<td>-3.30</td>
<td>From triple trade off curves</td>
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<tr>
<td>Margin</td>
<td>Margin</td>
<td>dB</td>
<td>0.54</td>
<td>𝑃_𝑂𝑀𝐴 − 𝑃_𝑀𝐼𝑁,𝑂𝑀𝐴</td>
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</tbody>
</table>

* Wavelength of 846nm was assumed for eye safety limit calculation using the worst case conditions; actual devices will generally have higher allowed power than this conservative value.

Table 2

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Units</th>
<th>Value</th>
<th>Equation</th>
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</thead>
<tbody>
<tr>
<td>Low Temperature</td>
<td>𝑇_𝐿</td>
<td>°C</td>
<td>-40</td>
<td>-</td>
</tr>
<tr>
<td>High Temperature</td>
<td>𝑇_𝐻</td>
<td>°C</td>
<td>85</td>
<td>-</td>
</tr>
<tr>
<td>Maximum average open bore power*</td>
<td>𝑃_𝑂𝐵,𝑀𝐴𝑋</td>
<td>dBm</td>
<td>0</td>
<td>Receiver limitiation</td>
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<tr>
<td>Coupling efficiency</td>
<td>𝜂_𝐶ＯＵＰ𝐿𝐼𝑁𝐺</td>
<td>dB</td>
<td>-1.5</td>
<td>-</td>
</tr>
<tr>
<td>Monitor diode Tracking error</td>
<td>Δ𝑇𝑅𝐴𝑁𝐾</td>
<td>dB</td>
<td>0.25</td>
<td>-</td>
</tr>
<tr>
<td>Coupled optical power</td>
<td>𝑃_𝐶ＯＵ𝑃𝐿𝐸𝐷</td>
<td>-</td>
<td>-1.67</td>
<td>𝑃_𝑂𝐵,𝑀𝐴𝑋 + 𝜂_𝐶ＯＵＰ𝐿𝐼𝑁𝐺 + Δ𝑇𝑅𝐴𝑁𝐾</td>
</tr>
<tr>
<td>Extinction ratio</td>
<td>ER</td>
<td>dB</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>Coupled OMA</td>
<td>𝑃_𝑂𝑀𝐴</td>
<td>dBm</td>
<td>-1.5</td>
<td>See previous equations</td>
</tr>
<tr>
<td>Min coupled OMA</td>
<td>𝑃_𝑀𝐼𝑁,𝑂𝑀𝐴</td>
<td>dBm</td>
<td>-3.30</td>
<td>From triple trade off curves</td>
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<tr>
<td>Margin</td>
<td>Margin</td>
<td>dB</td>
<td>1.8</td>
<td>𝑃_𝑂𝑀𝐴 − 𝑃_𝑀𝐼𝑁,𝑂𝑀𝐴</td>
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</tbody>
</table>

If, on the other hand, the module can be designed for class 1M operation, the eye safety concerns are greatly mitigated, and a much more reasonable launch budget analysis can be used. The difference is due to the change in aperture dimensions. (Class 1 is a 7mm aperture at 14mm, while Class 1M is a 7mm aperture at 100mm distance) For the purposes of our calculations, we have assumed a maximum fiber coupled power of −1.5dBm, which represents a open bore power of 0dBm. Changing only this value in the previous analysis increases the margin by 1.3dB. This analysis is intended for comparison, and is not intended as a guarantee. Please contact AOC for specific eye safety calculations. AOC does not certify products for eye safety, it is up to the user to make this certification.
Typical TOSA DC Performance Characteristics

The following is a sampling of some of the DC performance and is intended only as a reference guide. Always refer to the latest AOC TOSA and ROSA specifications available on the AOC VCSEL website http://www.adopco.com. Figure 10 includes representative fiber coupled light output (A) and forward voltage (B) as a function of laser current characteristic, and the monitor photodiode current as a function of laser optical power (C) over the temperature range of 0 to +85°C. Figure D is a plot of the optical power at a fixed average current as a function of temperature. Figures E through H are extracted parametric dependencies (slope efficiency, series resistance, threshold current and tracking ratio) from figures A, B and C.
From the data measured above, predictions on how the VCSEL can best be compensated over temperature are possible. In general, AOC recommends the use of an average power control circuit that can adjust the bias current to the laser to hold a fixed power output (monitor current). This effectively handles the parabolic threshold characteristics. However, the linear change in slope efficiency over temperature must also be compensated in order to maintain suitable optical modulation amplitude over the expected temperature range. Using the data above, and assuming that an OMA of \(-2\)dBm was set at room temperature, the predicted OMA values for various amounts of slope efficiency compensation is shown in figure 11. In order to effectively operate over the entire temperature range, it is best to closely match the actual slope change with temperature. However, if it is only the upper ends of the temperature range that are of interest (as is more typically the case in indoor installations), then over correction of the slope efficiency change with temperature might be beneficial to device operation. In this example, the measured data indicates a \(-0.3\%/\text{C}\) change in the slope efficiency with temperature, and does in fact yield the most stable results over the entire temperature range (green line), while the over corrected slope yields the smallest change over the 0 to 70°C range (purple line).

![Typical TOSA AC Characteristics](image)

**Figure 11**

**Typical TOSA AC Characteristics**

Eye diagram measurements at AOC are typically done in a benchtop setup using a pattern generator to directly drive the VCSEL cathode. A dc current source is used to set the average power from the VCSEL through the inductive channel of a bias tee. The modulation signal is a voltage level coming from the pattern generator, which is source terminated with 50Ω that is AC coupled to the VCSEL through a bias tee. The voltage is adjusted to set the OMA value. A schematic and picture of the test configuration is shown in figure 12.
Typical eye diagrams are depicted in figure 13 on the following page, over temperature measured with this test configuration. The monitor photo-diode current was held constant during the tests. The modulation voltage was adjusted to maintain the OMA. Each mask of the eye includes 10% margin.
Figure 14 is a plot of the measured RMS spectral width of a typical VCSEL operating a constant power of $-1 \text{dBm}$ over the temperature range of $-40$ to $+80^\circ \text{C}$. Inset into the figure are the measured spectra at $-40$, $25$ and $80^\circ \text{C}$. The values reported here are measured using the FOTP 127 style measurements. The unique design of the AOC VCSEL enables the user to meet the triple trade off curves of IEEE 802.3ae as described earlier.

![Figure 14](image_url)

**Foregoing the use of APC**

Average power control circuits have worked very well at lower data rates, but may not be appropriate for use in the 10Gbps applications. As described earlier in this application note, the launch power budget for class 1 eye safety is quite restrictive. In addition, obtaining high quality optical eye diagrams and very high reliability standards are often conflicting. Another approach is to use a prescribed bias current across temperature which can be programmed through a EEPROM. This approach has the advantage of being able to increase and decrease the average current in the VCSEL to optimize both eye diagrams and reliability. Consider the example below, where eye diagrams were collected using an average power control scheme and a programmable bias scheme. In all cases, the OMA value was maintained at $600 \text{mW}$.

As can be seen in the eye diagrams, figure 15, the APC circuit does not provide the optimal eye diagram for each of the tested temperatures. The general problem statement is that the device is under-driven at low temperatures to achieve the best eye quality, and over driven at high temperature to achieve the best reliability. Figure 16 summarizes the measured jitter and overshoot as a function of the current normalized to threshold at temperatures of $0$, $25$, $50$, and $85^\circ \text{C}$. 
The key point from these graphs is that appropriate levels of overshoot and jitter (and therefore eye quality) can be achieved at much lower currents relative to threshold as the temperature is increased. This indicates that the bias current can actually be reduced as the temperature increases and still maintain good eye quality. Reduction in the bias current at elevated temperature will result in improved reliability. The data also indicate that it may be necessary to increase the bias relative to threshold as the temperature decreases in order to maintain good eye quality. A sampling of the eye diagrams used to generate this data is shown in the figure 17.
Furthermore, this data can be used to calculate a relative speed factor as a function of the bias current for the cases of average power control, and programmable bias control. This is plotted in figure 18.
Finally, the impact of bias control can be measured in reliability terms. By reducing the current by 1mA at the high temperature, nearly a factor of 2 in reliability can be achieved. This is depicted in the figure 19, where the time to 1% failure is plotted for the APC scheme (blue diamonds) and the bias control scheme (red squares).
Recommended Transmitter Setup Conditions

In a typical application of Ethernet, AOC recommends that the user set the optical transceiver for class 1M eye safety operation. This can be accomplished by first setting the average fiber coupled power at room temperature at −1.5dBm using the bias adjustment on the laser driver. The modulation current amplitude should be adjusted to obtain an OMA value of approximately −1.5dBm, or an extinction ratio of approximately 5dB. If desired, temperature adjustment to the average power should be done using the backmonitor photodiode and the laser bias current to maintain a constant optical power over temperature. However, it is recommended that a current clamp of 10.5mA be used in order to preserve reliability at high temperatures, and to prevent operation close to power rollover in the VCSEL. If operation over the extended temperature range of −40 to +85°C is required, then careful matching of the slope efficiency tempco is necessary. Otherwise, for applications from 0 to 70°C, over correction of the slope efficiency change will yield the most stable OMA performance. However, this may yield an excessive ER at high temperature and lead to an increase in the deterministic jitter. Figure 20 demonstrates the performance of the TOSA for several set up conditions of ER and $P_{AVE}$ at room temperature. As described earlier, programmable laser bias as a function of temperature can be very advantageous in achieving excellent eye quality and reliability over temperature.

![Figure 20: Performance of the TOSA for various conditions of ER and $P_{AVE}$](image_url)
As can be seen in the figure 20, the eye quality generally increases with increasing $P_{\text{AVE}}$ and decreasing ER. For a more detailed discussion of the effects of extinction ratio and $P_{\text{AVE}}$ on the optical output, the reader is referred to the AOC application note “Modulating AOC Oxide VCSELs,” available at www.honeywell.com/vcsel. Table 2 summarizes the expected setup conditions for a typical AOC 10Gbps TOSA.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{\text{AVE}}$</td>
<td>dBm (mW)</td>
<td>-1.5 (0.708)</td>
</tr>
<tr>
<td>OMA (ER)</td>
<td>dBm (mW)</td>
<td>-1.5 (708)</td>
</tr>
<tr>
<td>$I_{\text{MOD Tempco}}$</td>
<td>%/°C</td>
<td>-0.3</td>
</tr>
<tr>
<td>$I_{\text{BIAS}}$</td>
<td>mA</td>
<td>7.5</td>
</tr>
<tr>
<td>$I_{\text{MOD (pk-pk)}}$</td>
<td>mA</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 2

**Use of Electrical Peaking Circuits**

One problem with optical compliance testing is creating a reference transmitter that has extremely fast rise and fall times. One method to achieve faster response times in a VCSEL is to introduce a peaking circuit on the electrical driving waveform. The peaking circuit helps to push and pull charge out of the capacitor storage in the VCSEL. Consider the circuit configuration shown figure 21, where a simple RC network has been added to the VCSEL drive path. Simulation of this circuit for frequencies of 10GBps and 5Gbps are shown as well.
The effect of the peaking circuit has also been verified experimentally, and this is shown on the next page. Also, a peaking circuit can be generated with cabling, attenuators, and power couplers. This is shown schematically in figure 22, and results are collected in figure 23.
Typical ROSA Characteristics

The mechanical and electrical interface of the AOC ROSA is very similar to that described earlier, and will not be repeated here. AOC is continuously evaluating commercial transimpedance amplifiers for use in the 10GB product. AOC is also providing solutions using a customer preferred transimpedance amplifier. The sections that follow provide the user with general information to calculate receiver performance based on the datasheet parameters provided by AOC. The interface circuit may also be specific to various TIA used. Refer to the AOC receiver data sheets available at www.adopco.com for detail specifications and performance characteristics. Figure 24 demonstrates the current BER performance of the 850nm ROSA with (red curve) and with-out (blue curve) a logic amplifier in the measurement system. Typical sensitivity values for the 1310nm/1550nm ROSA are 1 to 2dB better due to the difference in photodiode responsivity.
Figure 24

Recommended ROSA interface configuration

The receiver assembly for both the long wavelength and short wavelength versions are identical with the exception of the photodiode. It is recommended for maximum efficiency and sensitivity that the receiver be used differentially. The output stages of the preamplifier must be AC coupled and terminated in a 50Ω environment, and will not drive a DC terminated line. The RSSI signal is obtained through a separate bias line to the photodiode. A typical interface schematic is shown in figure 25, with the recommended power supply filtering circuit. It is further recommended that the inductor be an equivalent ferrite bead to ensure there is power dissipation and damping in the filter.

Figure 25
Estimating Receiver Sensitivity

In order to accurately estimate the receiver sensitivity for an optical system, it is important to consider all of the relevant components, such as the optical lensing system, the photodiode, the transimpedance amplifier, and the input sensitivity level of the logical components that follow. The analysis below is intended to take all of these variables into account; however, the accuracy for any particular application is not guaranteed. One thing to note here is that the analysis only takes into account vertical eye closure, and not horizontal eye closure from the various timing jitter sources. The analysis will also only consider gaussian statistics for error probability, where for a given signal to noise ratio, Q, the probability that an error will occur is given by,

\[ P(Q) = \frac{1}{2} \left( \text{erfc} \left( \frac{Q}{\sqrt{2}} \right) \right) \]

Therefore, to achieve a probability \( P(Q) \) of bit errors < 10\(^{-12}\), then \( Q > 7 \). However, this only considers the noise from one of the logical states. When both logical states are considered, then \( Q > 14 \) is necessary to achieve an error rate < 10\(^{-12}\). The blocks that must be considered in this analysis are the optical signal, the photodiode, the transimpedance amplifier, and the logical circuitry to follow. For simplicity, this analysis will assume an input amplitude sensitivity to the logical circuitry, and that a \( Q > 14 \) as sufficient to achieve error rates < 10\(^{-12}\). The function blocks are depicted in figure 27.

The receiver sensitivity can then be estimated from the following necessary conditions,

\[ Q = \frac{I_{\text{LIGHT}}}{I_{\text{NOISE}}} > 14 \]
\[ V_{\text{OUT}} > V_{\text{SENSITIVITY}} \]
Where, $I_{\text{LIGHT}}$ (A) is the current generated by the light input into the photodiode, $I_{\text{NOISE}}$ (A) is the RMS noise current equivalent at the input node of the transimpedance amplifier, $V_{\text{OUT}}$ (V) is the output voltage level of the TIA, and $V_{\text{SENSITIVITY}}$ (V) is the input sensitivity of the logic circuitry. Each of the above variables is further defined as,

$$I_{\text{LIGHT}} = P_{\text{OPTICAL}}^\text{OMA} \cdot \eta_{\text{OPTICAL}} \cdot R_{PD}$$

$$V_{\text{OUT}} = I_{\text{LIGHT}} \cdot G_{\text{TIA}}$$

Where $P_{\text{OPTICAL}}$ is the optical modulation amplitude (OMA as defined earlier) in units of W, $\eta_{\text{OPTICAL}}$ is the efficiency of the optical lensing system, RPD is the responsivity of the photodiode (A/W), and $G_{\text{TIA}}$ is the transimpedance gain (V/A) of the TIA. Taken together, the sensitivity can be expressed then as,

$$\text{Sensitivity} = \frac{I_{\text{NOISE}} \cdot Q + V_{\text{SENSITIVITY}}}{R_{PD} \cdot \eta_{\text{OPTICAL}}}$$

Table 3 illustrates the calculation of receiver sensitivity. Please note that this document only considered ideal optical inputs, and that degradation in receiver sensitivity can be observed with degradation of the signal to noise ratio of the optical input. In addition, horizontal eye closure (jitter) effects on the receiver sensitivity. It has also assumed that the signal from the photodiode is “AC” coupled to the TIA. Refer to the AOC product data sheet for current parameters.

Note: AOC uses a COTS TIA, and is willing to customize the product offering with a TIA provided/required by a customer.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Typical Value</th>
<th>Worst Case Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{PD}$</td>
<td>A/W</td>
<td>0.58</td>
<td>0.56</td>
</tr>
<tr>
<td>$\eta_{\text{OPTICAL}}$</td>
<td>-</td>
<td>0.9</td>
<td>0.88</td>
</tr>
<tr>
<td>$G_{\text{TIA}}$</td>
<td>V/A</td>
<td>3000</td>
<td>2500</td>
</tr>
<tr>
<td>$I_{\text{NOISE}}$</td>
<td>A</td>
<td>1.0x10^-6</td>
<td>1.25x10^-6</td>
</tr>
<tr>
<td>$V_{\text{SENSITIVITY}}$</td>
<td>V</td>
<td>0.015</td>
<td>0.025</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>mW, OMA</td>
<td>0.0366</td>
<td>0.056</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>dBm, OMA</td>
<td>-14.36</td>
<td>-12.5</td>
</tr>
</tbody>
</table>

Table 3

**Designing for EMI Performance**

EMI performance of the optical transceiver is a detail of the mechanical, electrical, and optical system that is unfortunately often overlooked in initial design. The standard TOSA and ROSA offered by AOC is made from an unfilled plastic material. Unfortunately, this material offers little electromagnetic radiation shielding. Thus, it is imperative that the transceiver designer incorporate EMI design principles from the very first mechanical designs.
There are several apertures and radiation sources that should be considered. First is radiation from the TOSA and ROSA that emanate from the various bond wires in the package. Typically the bond wires inside the TO can are less than 1mm in length, and therefore are generally very low in radiation. The total power radiated, $P_{\text{RADIATED}}$, in Watts, from a simple wire can be expressed as:

$$P_{\text{RADIATED}}(W) = \frac{\pi}{3c^2} \eta L^2 f^2$$

where $c$ is the speed of light (3x10^8 m/sec), $\eta$ is the impedance of free space (377 $\Omega$), $I$ is the current in the wire (A), $L$ is the length of the wire (m), and $f$ is the frequency (Hz). For a closed loop antenna, the total power radiated can be expressed as:

$$P_{\text{Loop}}(W) = \frac{4\pi}{3c^4} \eta L^4 f^4$$

The total power radiated for a short wire and a loop antenna are plotted in figure 28 for a current of 10mA at each frequency. In practical cases, the current will be limited due to the finite electrical bandwidth of the TOSA and ROSA packages.

![Figure 28](image)

Radiation from a single wire or a loop wire that can escape the packaging is generally emitted from inside the TO can. EMI from this source can only be effected by the user through reduction of modulation current.

The second type of radiation emission sources that must be considered is emissions from the electronic circuitry that can escape through the front of the transceiver. This type of radiation is controlled by introducing significant EMI shielding, typically in the form of a conductive (grounded) surface. A general rule of thumb for electromagnetic emissions is that any openings in the shielding should be limited to less than one tenth the wavelength. For a 10Gbps (5GHz fundamental
frequency) system, harmonics to more than 50GHz are possible in the electrical signal. Thus, the worst-case opening should be limited to,

\[
Opening < \frac{\lambda_{\text{electrical}}}{10} = \frac{c}{f \sqrt{\epsilon}} \approx 1.5\text{mm}
\]

AOC recommends the use of metallic bezels in between the LC connector ports in the connector design, as well as potentially using a bezel in between the components near the circuit board connections. In the worst case for the LC connectors, in the absence of any shielding, the worst case effective on axis opening is about 0.5mm. For SC connectors, the worst case on axis opening is 5mm. (Note that these are projections based on the use of metallic components to hold the TOSA and ROSA) It is critical to include extensive EMI shielding between the TOSA and ROSA for the SC design.

To prevent electrical crosstalk between the TOSA and ROSA, it is recommended that customers contact the ground plane of the TOSA and ROSA package to both analog and digital ground of the transceiver. Users should be careful to minimize noise on the transceiver ground plane by utilizing significant capacitive decoupling and controlled impedance wherever practical. It is also often beneficial to provide power dissipation in the decoupling, such as ferrite beads in place of inductors. Because of the close proximity in mounting of the TOSA and ROSA for duplex operation, it is further recommended that the ROSA electrical interface be surrounded by a grounded EMI cage. If possible, the power supplies for the TOSA and ROSA should be separated and capacitively decoupled to ground to minimize any potential for electrical crosstalk between the components. There is no possibility of optical crosstalk between the components.

Reliability

The reliability of AOC VCSELs is determined by two interdependent parameters, the temperature of the active region, and the total current density. AOC has developed a VCSEL reliability model that has been validated in both oxide and proton VCSELs, and for multiple aperture dimensions and several internal configurations [8]. To a first approximation, the reliability goes as the inverse square of the current density, which would dictate that the VCSEL should be operated at the lowest possible current. However, the intrinsic speed of the VCSEL increases with the square root of the current density, indicating that higher current density is better for performance. The figure below displays the design tradeoffs.

NOTE: this set of curves does not represent typical AOC devices, but is intended only as an educational tool for reliability and speed trade-off discussions. Contact AOC for specific reliability calculations.
In figure 29, the x-axis is the normalized current above threshold; the first Y-axis is the calculated Mean Time to Failure (MTTF) in hours at temperatures of 0, 40, and 80°C, and the second Y-axis (shown in Red) is the relaxation oscillation resonant frequency in GHz.

The final point to be made on reliability is the practical limits for the emitted optical power are also restricted by the various optical standards on the low end for power budgeting in the link, and on the high end to maintain eye safety compliance. AOC removes the power limitations at the upper end by providing TOSA assemblies with intentionally reduced optical power.

Recent work at AOC has focused on increasing the speed of a VCSEL at a fixed current density. The reliability analysis above is valid for a particular design of VCSEL, and must be re-evaluated for new designs. Figure 30 demonstrates the improvement that AOC has made in achieving open eye diagrams at 10GBd at reduced current densities, which is key to increasing reliability of the VCSEL.
The reliability of AOC VCSELs operating at 10Gbps is constantly under investigation and improvement. Visit http://www.finisar.com/aoc.php for the current reliability metrics. Finally, the reliability can be further improved with the use of programmable bias control, and limiting the average current at high temperature.

Using the AOC TOSA and ROSA Evaluation Boards

The 10GB VCSEL samples are provided attached to an evaluation board for rapid evaluation and ease of use by the customer. There are three board configurations, anode driven, cathode driven, and differential driven. All of the boards have a common attachment means for both the TOSA and the ROSA. Referring to Figure below, the TOSA/ROSA may be removed/replaced by

1. Remove the knurled screws holding the black contact bar in place.
2. Gently remove the flex from the board by pulling upwards. Note that there are alignment pins for the flex on the board. Electrical contact is made by pressure from the contact bar.
3. Replace TOSA/ROSA with a new part to be evaluated
4. Replace contact bar, and tighten nuts holding bar in place

To remove the LC lens barrel assembly from the LC connector plug, remove the black plastic insertion bar located on the bottom of the package, and gently pull the component out of the connector mating assembly.

Electrical Connections

The evaluation board was originally designed to handle both single ended TOSAs and differential ROSAs at the same time. Subsequent testing has indicated that the single ended trace is significantly lower in bandwidth than the differential signal connections. It is therefore recommended that both TOSAs and ROSAs be connected to the differential traces, and the single ended trace not be used. Therefore, the user will need separate evaluation boards for the TOSA and ROSA. The electrical connections are detailed in figure 31.

**Anode Driven Part**

To test the TOSA component, connect a current meter between the monitor diode cathode and ground. A bias voltage is not required for the monitor diode. Using a high frequency bias tee such as the Picometrix 5541A, connect the pattern generator output to the AC leg of the tee, and connect a constant current source to the DC leg. The cathode contact should be terminated with a 50 ohm load.

**Cathode Driven Part**

To test the TOSA component, connect a current meter between the monitor diode cathode and ground. A bias voltage is not required for the monitor diode. Connect a high frequency bias tee such
as the Picometrix 5541A to the cathode of the VCSEL. Connect the pattern generator output to the AC leg of the tee, and connect a constant current source to the DC leg. The anode contact should be terminated with a 50 ohm load. The cathode driven VCSEL includes a capacitor inside the TOSA.

**Differential Driven Part**

To test the TOSA component, connect a current meter between the monitor diode cathode and ground. A bias voltage is not required for the monitor diode. Connect a high frequency bias tee such as the Picometrix 5541A to both the anode and the cathode of the VCSEL. Connect the outputs of the pattern generator to the AC legs of the bias tees, and connect a constant current source between the DC legs of the bias tee. Differential driven parts are available with either 25 or 50 Ohm transmission lines.

**ROSA Connection**

The HFD6x80 ROSA can also be evaluated on this board. Power supply filtering for both the Vcc and Vpd connections has been provided on the board. To test the ROSA, connect a 3.3V source to the Vcc connection. Next, connect a 3.3V source to the Vpd, this is the power supply for the PIN photodiode. (Please note that labeling on the board is incorrect) Current into this pin is the average current in the PD. Connect a high frequency bias tee (or DC block) such as the Picometrix 5541A to both the differential outputs. Do not connect the DC leg of the bias tee to a power supply. The bias tee is simply used as an AC coupling from the TIA. Connect the outputs of the TIA to a 50Ohm terminated load, typically an oscilloscope, error detector, CDR, etc. Ensure that both sides of the TIA are terminated or the ROSA may become unstable.

**Optical characterization**

Connect an LC fiber into the receptacle, and connect the other end to the optical input of an oscilloscope, or other suitable detector. Adjust the DC current level to achieve the desired average optical power, typically –3dBm. Adjust the amplitude of the pattern generator output to achieve the proper optical modulation amplitude or extinction ratio. For more information on typical set points, please refer to the earlier sections of this application note.

**References**

[1] IEEE 802.3ae 10GB Ethernet specifications


[5] TIA FOCIS 604-3a specifications
[6] TIA FOCIS 604-10 specifications


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.

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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