MAX3735A Laser Driver Output Configurations,

Part 4: Driving VCSELs

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1   Introduction

The MAX3735A is a DC-coupled SFP laser driver designed for data rates up to 2.7Gbps (reference 1). The multi-rate capability, small package, APC loop, SFP safety/timing specifications and monitor outputs of the MAX3735A make it suitable for a large variety of optical module applications operating over a wide range of data rates. The output of the MAX3735A is intended to drive DC-coupled, edge-emitting, common-anode lasers, but it can also be used to drive a variety of other laser configurations (reference 2, 3).

This design note (Part 4 of a series of notes) will discuss driving a VCSEL in detail. The purpose of this application note and others in the series is to examine the advantages and disadvantages of the various output configurations, and to provide schematics and examples that will help module designers choose the optimal output structure for their application.

The MAX3735A will be used as an example to discuss these interfaces, but the techniques can be applied to other laser drivers such as the MAX3737, MAX3735, MAX3850 and MAX3656, due to their similar output structures.

2   Driving VCSELs

Vertical Cavity Surface Emitting Lasers (VCSELs) are commonly used in Ethernet and other short reach applications. There are many laser drivers specifically intended for VCSELs such as the MAX3740, MAX3741 and MAX3996. The purpose of this application note is to demonstrate how to drive a common anode or isolated VCSEL using the MAX3735A for those that wish to use one driver for both edge-emitting laser and VCSEL applications.

2.1   VCSELs with MAX3735A Advantages

1. **One Part For Multiple Applications** – Using the MAX3735A with VCSELs allows module manufacturers to use one driver IC with multiple module applications (i.e. Ethernet, SONET, Long Reach, Short Reach, etc.).

2. **Increased Modulation Currents** – Using the MAX3735A allows larger drive currents than conventional VCSEL drivers.

2.2   VCSELs with MAX3735A Disadvantages

3. **AC Coupling** – The forward voltage and series resistance of a typical VCSEL is larger than an edge-emitting laser diode. These factors make DC coupling the laser to the driver more constrictive or impractical. The downside to AC coupling is that it introduces a low-frequency cutoff that can cause jitter and baseline wander. See section 3.3 for more information.

2.3   Vertical vs. Edge-Emitting Lasers

VCSELs differ from edge-emitting lasers in several parameters such as series resistance, forward voltage and slope efficiency. These parameters will greatly affect what types of output configurations can be used to drive the laser as well as indicate the levels of drive currents that are required.

2.3.1   Series Resistance

An edge-emitting laser typically has a series resistance of 4Ω to 7Ω. The series resistance of a VCSEL is related to the number of layers used in its construction. To operate at higher data rates, more layers are needed which causes the series resistance to increase. A VCSEL used in 10Gbps applications

for example, can have a series resistance of 45Ω to 80Ω while one intended for 1 or 2Gbps applications is generally 20Ω to 50Ω.

2.3.2 Forward Voltage

The forward voltage of a VCSEL (Typically 1.8V) is higher than a standard edge emitter (Typically 1.2V). If the forward voltage of the VCSEL is too large, it may not be possible to DC couple the laser to the laser driver. The MAX3735A requires that the minimum instantaneous voltage at its output be no less than 0.7V.

Figure 1 shows the static bias voltage when using a VCSEL. Under worse-case conditions (minimum supply and maximum forward voltage) of a typical VCSEL, the voltage at the output would be only 0.77V. This leaves only 0.07V for modulation current to pass through the VCSEL and any parasitic inductance in the signal path. These factors would limit the attainable modulation current to just a couple of milliamps (assuming 30Ω VCSEL impedance). Given the larger forward voltage of VCSEL, AC coupling the VCSEL to the driver is generally required when using a +3.3V supply with a +/- 10% variation.
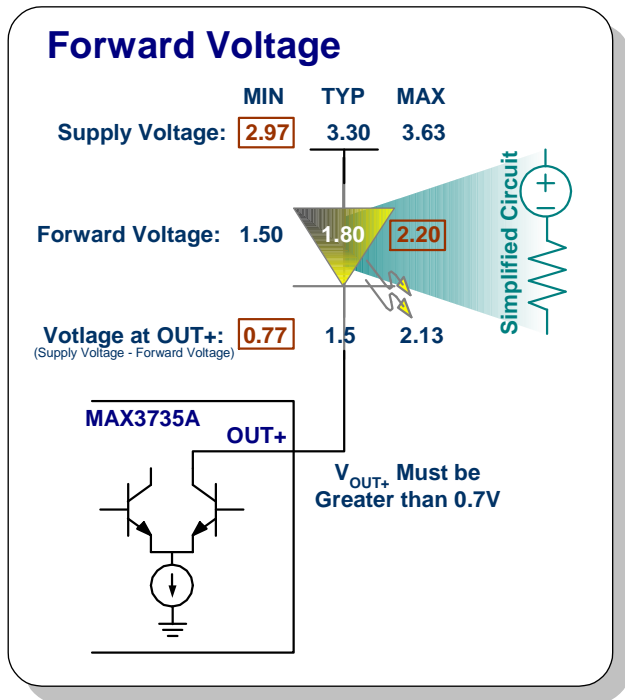

Figure 1. Forward Voltage

2.3.3 Slope Efficiency

The slope efficiency of a VCSEL is generally higher than that of an edge-emitting laser. The improved efficiency requires less modulation and bias current from the laser driver. In some cases the modulation and bias current required for a VCSEL may be lower than the specified minimums that the driver can deliver.

The MAX3735A, for example, has a minimum modulation current of 10mA. A typical VCSEL is modulated with 5 to 25mA. Using AC coupling and pull-up resistors, the modulation current delivered to the VCSEL can be reduced.

3 Driver Output Configurations / Special Considerations

A VCSEL can be driven with a DC-coupled, AC-coupled or differential drive configuration. However, there are limitations on the types of VCSELs that can be used in DC-coupled or differential drive configurations. For this reason, only the AC-coupled output configuration will be discussed in this application note.
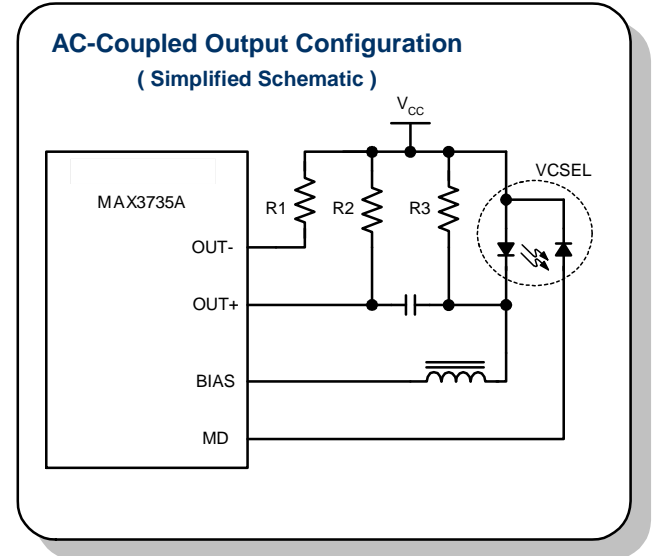

Figure 2. AC-Coupled Configuration

3.1 AC-Coupled Output

The basic schematic connections of an AC-coupled VCSEL output network are shown in Figure 2. R2 is added to direct modulation current away from the laser and to lower the overall AC impedance of the

load. Additionally R3 may be added to reduce the bias current delivered to the laser and will also direct some modulation current away. The purpose of R3 is more fully explained in section 3.3 Automatic Power Control (APC) Loop. The parallel combination of the R2, R3 and VCSEL series resistance should be 15Ω to 25Ω. In a typical application, R2 should be between 25Ω and 75Ω and R3 should be greater than 100Ω. R2 and R3 should also be selected so that an acceptable amount of current is delivered to the laser (Figure 3).
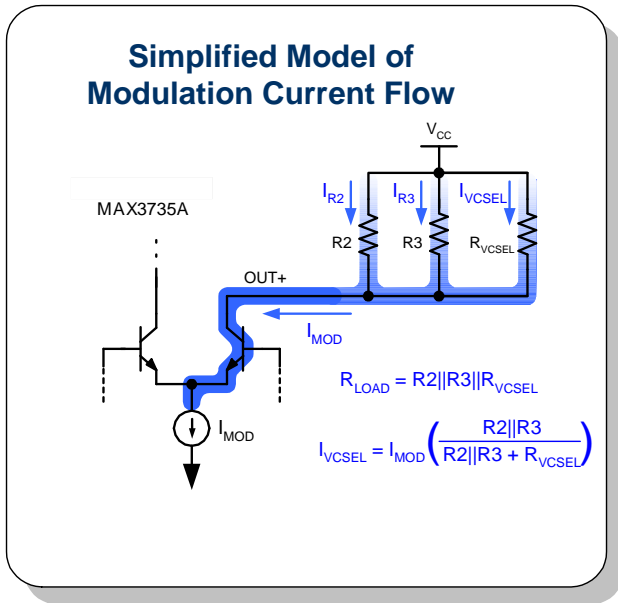

Figure 3.   Modulation Current Model

3.2   Laser Gain and APC Loops

VCSEL assemblies used in high-speed communication systems will generally include a monitor diode. The monitor diode is a photodiode that produces a current (I_{MD}, Figure 4) proportional to the average optical output power. The automatic power control (APC) loop of a laser driver adjusts the bias current in order to maintain a constant monitor diode current (I_{MD}) which translates to a constant average optical power. The ratio of I_{MD} to the average lasing current ($I_{BIAS} - I_{THRESHOLD}$) is known as the gain (Figure 4) of the VCSEL.

The gain of a VCSEL is typically larger than that of an edge-emitting laser. The APC loop of the MAX3735A was designed for laser gains between 0.005 and 0.045. If possible, the gain (seen by the MAX3735A APC loop) should be reduced to less than 0.045. This can be done using the R3 resistor in

Figure 4. The bias current will be divided between the R3 resistor and the VCSEL. The gain (seen by the APC loop) is reduced since the bias current through R3 will not translate to monitor diode current (Figure 4).
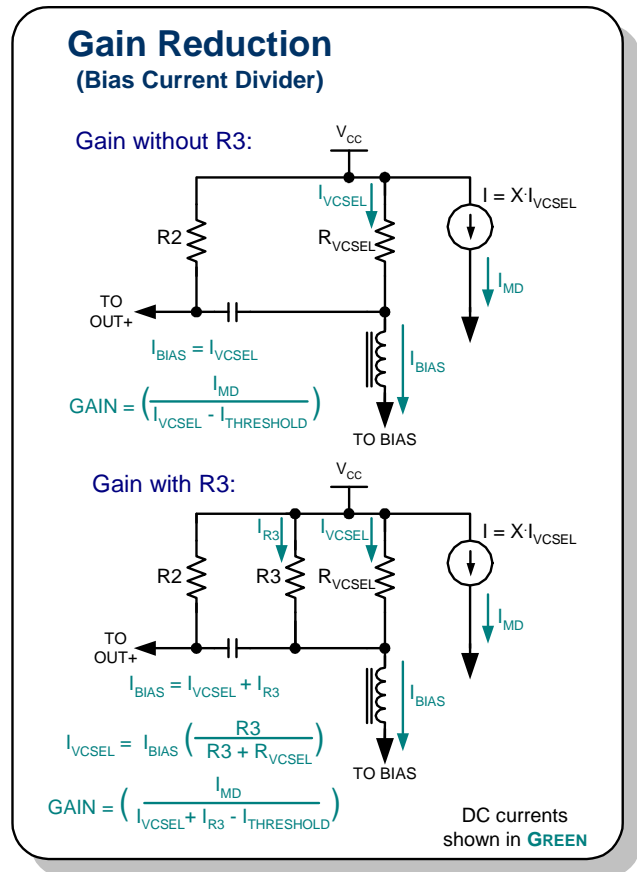

Figure 4.   Gain Reduction

If the gain can not be reduced below 0.045 using the R3 resistor, the APC loop capacitor should be increased in order to maintain stability. For more information on choosing the APC loop capacitor, see reference 4.

3.3   Low-Frequency Cutoff

The AC-coupled output configuration introduces a low-frequency cutoff that can cause jitter and baseline wander (Reference 5, 6). Table 1 shows suggested AC-coupling capacitor (C_{AC}) values for various applications to minimize these affects.

Table 1. Suggested Capacitors

Ethernet or Fibre Channel Patterns	
Data Rate $\geq$ 2.125Gbps	$C_{AC} \geq 0.01uF$
Data Rate $\geq$ 1.0625Gbps	$C_{AC} \geq 0.1uF$
SONET Patterns	
Data Rate $\geq$ OC48	$C_{AC} \geq 0.1uF$
Data Rate $\geq$ OC24	$C_{AC} \geq 0.22uF$
Data Rate $\geq$ OC24	$C_{AC} \geq 0.47uF$
Data Rate $\geq$ OC3	$C_{AC} \geq 1uF$

3.4   Matching Networks

When modulating lasers at gigabit data rates, a matching network is often needed to reduce ringing and overshoot on the output. Figure 5 illustrates some of the locations/methods that can be used. The values of the components should be determined experimentally, but will often range from 0.5pF to 10pF for the capacitor (C1) and 30Ω to 75Ω for the resistor (R1) in option 1, and 100Ω to 200Ω for the resistor (R2) in option 2.
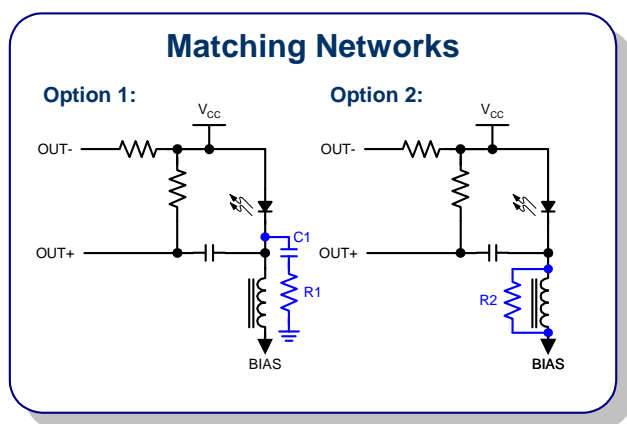

Figure 5.   Matching Networks

The matching network should be optimized while finding a balance between overshoot and rise/fall times. Increasing the capacitance or decreasing the resistance in the networks will reduce the overshoot and slow down the edge speeds.

4   Layout Techniques

To obtain good results at gigabit data rates, factors such as laser package, component placement and the current return path should be carefully evaluated.

4.1   Laser Package and Connections

Parasitic inductance and capacitance of the laser and external components will degrade the performance.

The inductance and capacitance in the modulation path should be reduced as much as possible when modulating laser diodes at gigabit data rates.

Using short connections from the laser driver to the laser, short leads (for a TO-style package) or improved laser packages will reduce the series inductance. When possible, a TO-style laser should be edge mounted to eliminate the parasitic affects of the through-hole connections.

4.1.1   Edge Mounting the Laser

It is common in circuit board design to pull the ground and power plane back from the physical edge of the board. But, when connecting a TO-style laser to the edge of the board, the ground plane should extend to the edge of the board that interfaces with the laser (Figure 6). Extending the ground plane will reduce the inductance of the leads and improve the high-speed performance. If possible, the high-speed connections (laser anode and cathode) should be placed on the top of the circuit board to take advantage of the lower lead inductance created by the extended ground plane and to eliminate vias. The laser should also be mounted as close as possible to the edge of the board to reduce the inductance of the leads.
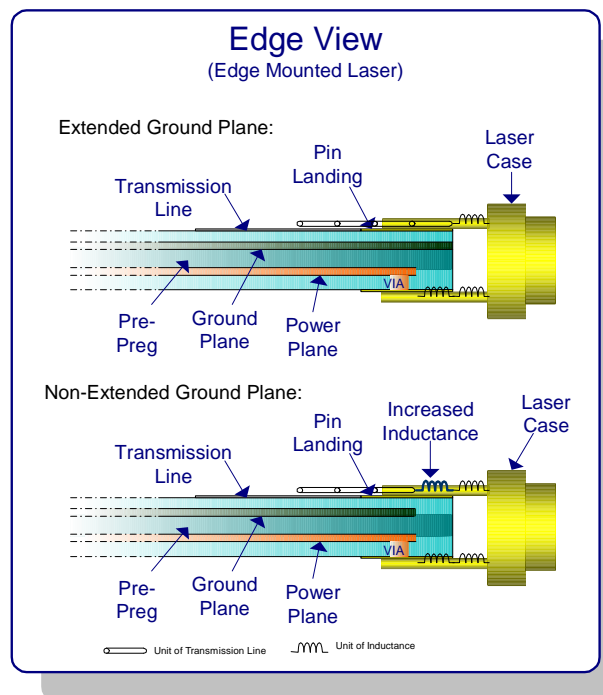

Figure 6.   Edge Mounting a Laser

4.2 Component Placement and Current Return Path

An important part of component placement is in evaluating the return path, current flow and filtering. Using Figure 8 as a reference, a possible component placement is shown in Figure 7. (Note: These configurations are suggestions only and should be evaluated and modified as necessary for each application.)
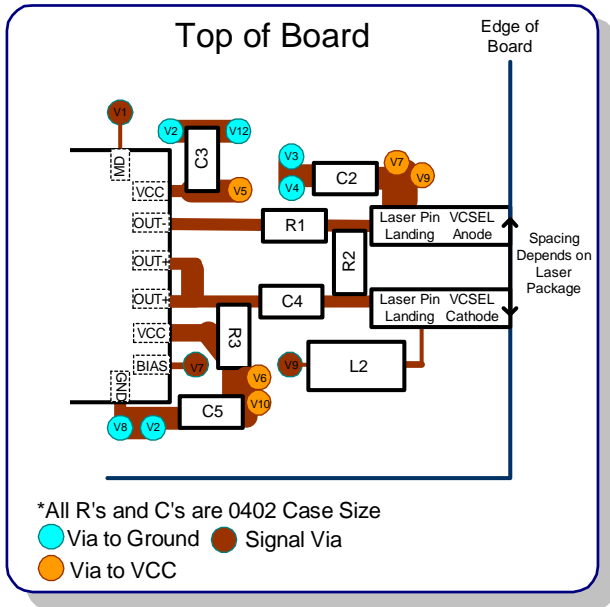

Figure 7. Possible Component Placement

Dedicated ground and power planes should be used. Using dedicated planes will lower the connection impedance and provide a better return path for the high-speed currents. The return path of the bypass capacitors should also be oriented (if possible) so the ground connection is close to the transmission line and the ground of the device.

The pull-up resistor (R2 in Figure 1) will have small amounts of high-speed switching current. R2 should therefore be terminated to V_{CC} with short connections and also be well bypassed.

5 Example

5.1 Schematics

To illustrate driving a VCSEL, an AC-coupled network with resistive pull-ups was built and tested with the MAX3735A and a Honeywell VCSEL (HFE4190-541, Reference 7). The schematic connections can be seen in Figure 8.
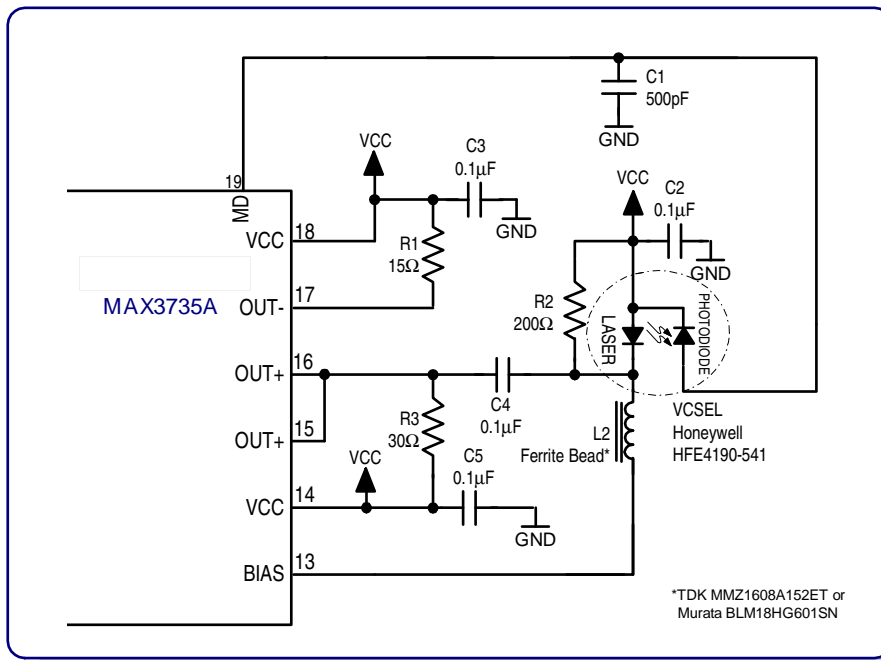

Figure 8.   Schematic

5.2 Test Data

Applying the suggestions above and the schematic shown in Figure 8, the following optical eye diagrams (Figures 9 - 12) were obtained. A matching network was not used. Depending on how the laser is connected to the board and the exact component layout, a matching network may be need. It is therefore recommended to leave space in the layout for one to be used if necessary (See section 3.4 for more details).
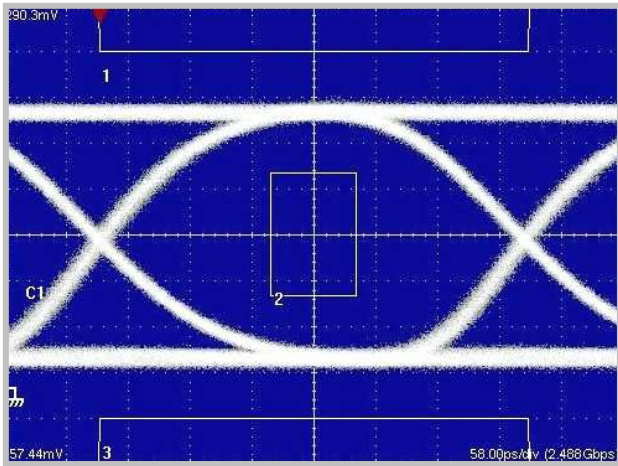

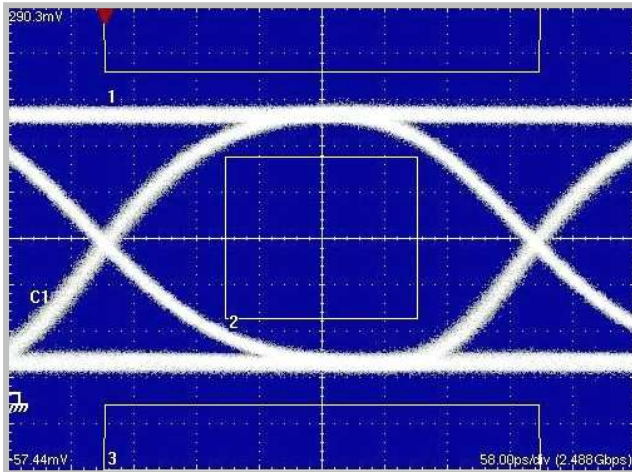*Figure 9. OC48 (Filtered), E_R > 9dB, 2^{23}-1PRBS, Standard Mask*

Figure 10. OC48 (Filtered), E_R > 9dB, 2^{23}-1PRBS, Shown with 30% Margin to Standard Mask

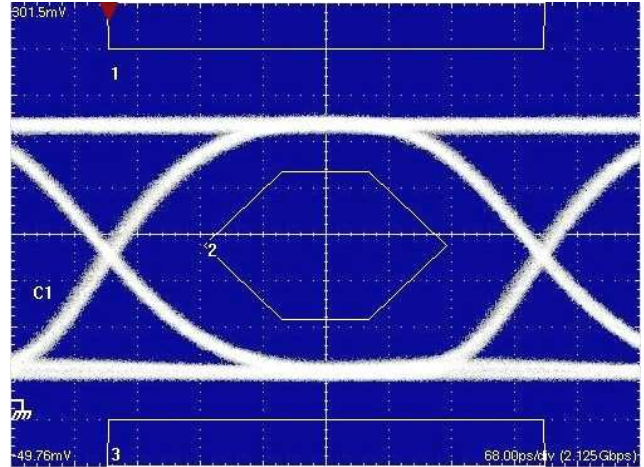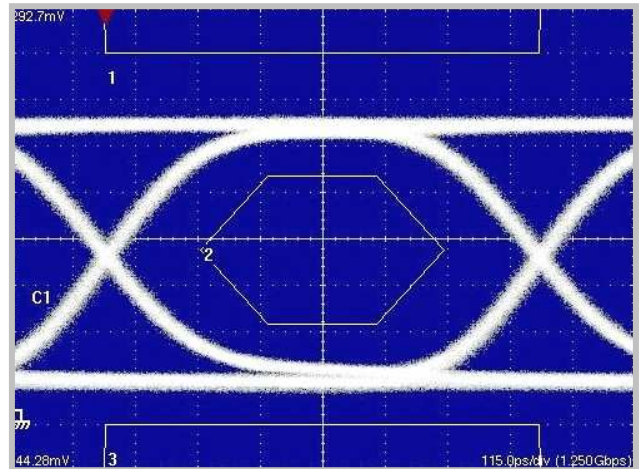*Figure 11. 2.125Gbps (Filtered), E_R > 9dB, 2^7-1PRBS, Standard Mask*

Figure 12. 1.25Gbps (Filtered), E_R > 9dB, 2^7-1PRBS, Standard Mask

6 Conclusion

The driving requirements of a VCSEL are different than those of an edge-emitting laser. Using the techniques and methods explained above, it has been shown that the MAX3735A edge-emitting laser driver can be adapted to also drive VCSELs at gigabit data rates. By adapting the MAX3735A for VCSELs, one device can be used in multiple module applications.

References:

1. Data Sheet: "MAX3735/MAX3735A: 2.7Gbps, Low Power SFP Laser Driver." - Maxim Integrated Products, May 2003.

2. Design Note: "MAX3735A Output Configurations, Part 1: DC-Coupled Optimization Techniques" – HFDN-26.0, Maxim Integrated Products, June, 2003

3. Design Note: "MAX3735A Output Configurations, Part 3: Differential Drive" – HFDN-26.2, Maxim Integrated Products, September, 2003

4. Design Note: "Choosing the APC Loop Capacitors Used with MAX3735 / MAX3735A SFP Module Designs" – HFDN-23.0, Maxim Integrated Products, September, 2002

5. Design Note: "Choosing AC-Coupling Capacitors" – HFAN-01.1, Maxim Integrated Products, October, 2000

6. Design Note: "NRZ Bandwidth – LF Cutoff and Baseline Wander" – HFAN-09.0.4, Maxim Integrated Products, September, 2002

7. Data Sheet: "HFE4190-541 VCSEL" – Honeywell, October, 2003