The Quest for Accurate Current Sensing

Introduction

Measuring the light output of a pulsed laser diode is not the best indication of the magnitude, temporal shape, and direction of the current flowing through the device. Voltage/current reversal, which can damage a laser diode, will not be visible on the output signal of a photodetector. Buyers should beware when a manufacturer of pulsed laser diode drivers shows only a photodetector output on a datasheet. This most likely indicates that the driver does not include an accurate current sensing circuit or has overshoot during turn-on or shut-off.

One option for the user is to measure the current through the laser diode with a high quality current monitor (transformer) such as ones manufactured by Pearson Electronics http://www.pearsonelectronics.com/). These monitors require one of the output leads of the driver to be looped through the monitor. If the extra inductance added by this connection (plus the load inductance) is less than the internal inductance of the driver then minimal pulse distortion will occur; however, for short pulse, low output inductance drivers, this added inductance could greatly distort the waveform and in fact might cause the current to reverse during shut-off. In this scenario, an attempt to measure the current results in more trouble than the benefit is worth. The user could also build a miniature current monitor to keep the added inductance as small as possible; however, these devices must be calibrated against a known current monitor. Most users want to spend their time working with the light output of their diodes and not designing circuits or test equipment; therefore, the most efficient and cost effective approach is to find a laser diode driver that provides accurate current sensing.

Accurate Current Sensing: Trickier Than You May Think

The most common method for current sensing is to use a current viewing resistor (CVR) in series with the laser diode. In an ideal world this would be a very straightforward method—simply measure the voltage across the resistor, and then divide by the resistance to obtain the current. For pulsed measurements, however, problems occur because the CVR, like all resistors, has parasitic capacitance and inductance. For pulsed measurements the parasitic inductance is the factor that can create problems, not in the magnitude of the inductance but in the ratio of the inductance to the resistance (L/R) that is the measure of the frequency response of the CVR. Take for example a 10 mOhm, 1206 surface mount resistor with a parasitic inductance of 1.2 nH. For this CVR to act as an accurate current sensing element, the L/R time (current rise/fall time) of the driver must be much greater than the L/R time of the CVR which is 120 ns. This can be explained by examining the circuit shown in Figure 1. Here a low resistance (<1 mOhm) laser diode bar (X1) is being driven by a pulsed voltage source with inductance *Lsource* and resistance *Rsource*. A 10 mOhm CVR is used to monitor the current in the laser diode. If the L/R time of the source is 100 times that of the CVR, the CVR voltage (V(OUT_CVR)) will be a reasonable facsimile of the current through the laser diode. Figure 2 plots the voltage across the CVR (V(CVR_OUT)) and the voltage across just Rcvr (V(OUT_IDEAL)), which is a true representation of the current through the laser diode. Figure 2 shows that both curves closely agree on the rising edge but there is a slight discrepancy during shut-off. This discrepancy is due to the voltage across the CVR inductance (*Lcvr**dI/dt) subtracting from the voltage across *Rcvr*.

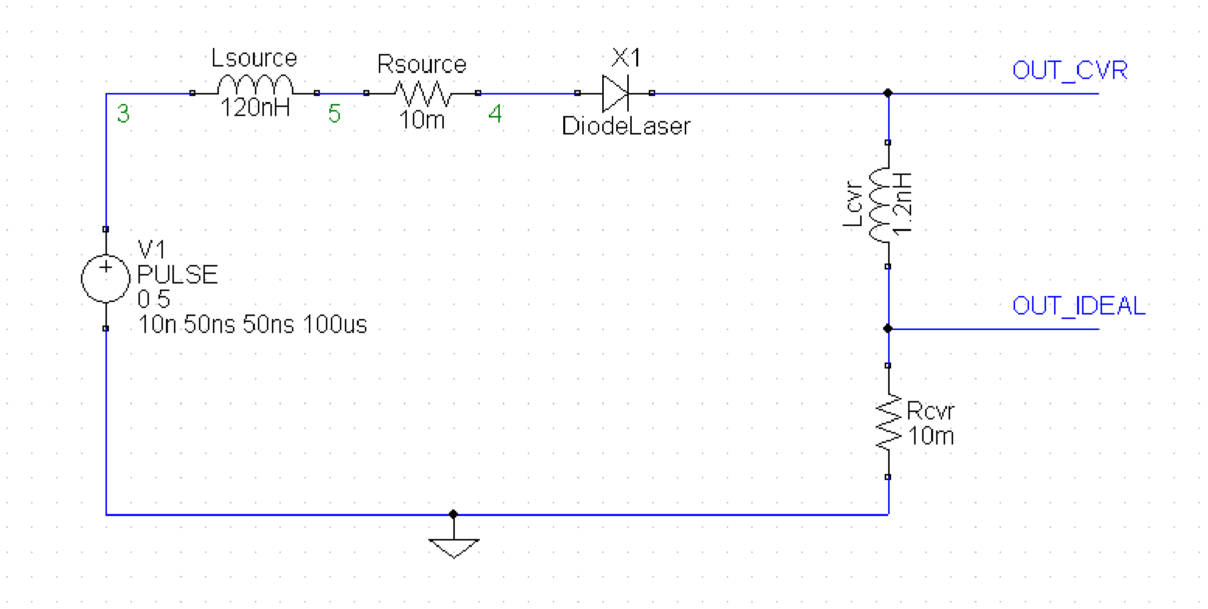

Figure 1. Schematic of a laser diode driver represented by a pulse generator (V1) with a source inductance (*Lsource*) and resistance (*Rsource*). The current is monitored by a CVR represented by an inductor (*Lcvr*) in series with a resistor (*Rcvr*).

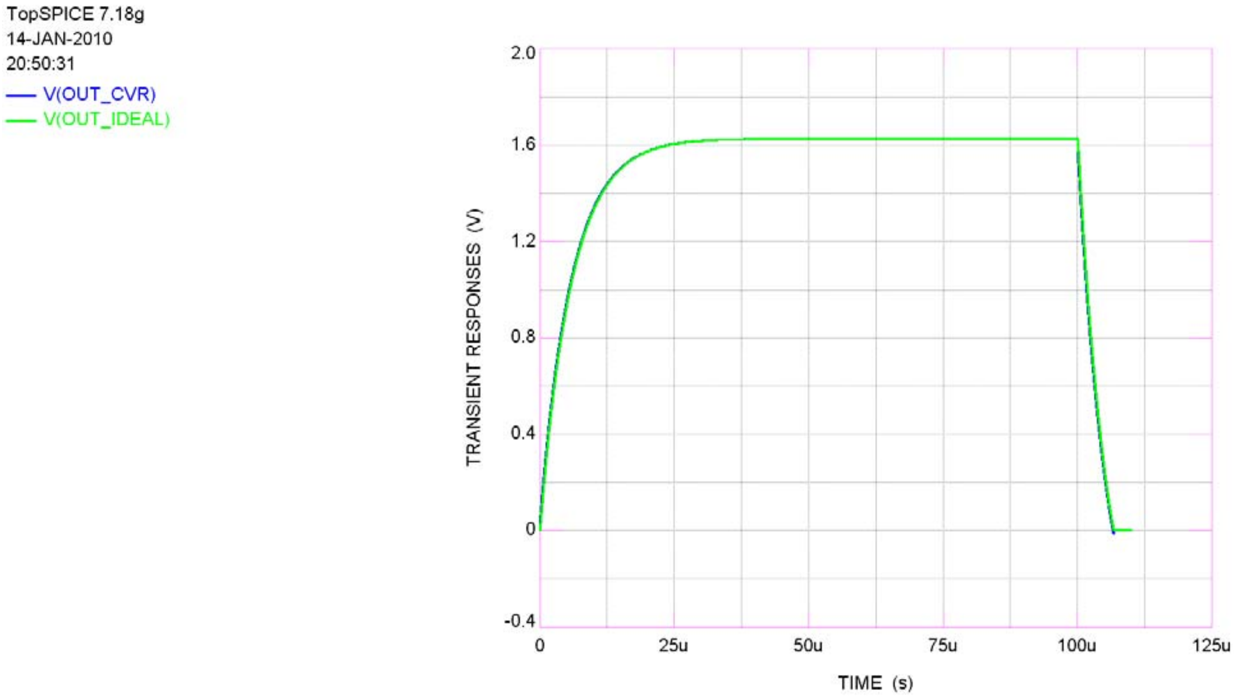

Figure 2. Voltage across the CVR (V(CVR_OUT)) and voltage across *Rcvr* (V(CVR_IDEAL)). For the case where the L/R of the source is 100x that of the CVR.

If we examine the case where the L/R of the source is equal to that of the CVR we see a completely different result. For this condition the voltage across the CVR is not a true representation of the current through the laser diode during both the risetime and the falltime. The waveform in Figure 3 shows significant overshoot in the measured CVR voltage compared to the actual current flow through the laser diode. Figure 4 shows that during the falltime of the pulse there is also significant undershoot caused by the voltage across CVR inductance which momentarily subtracts from the voltage across the CVR resistance.

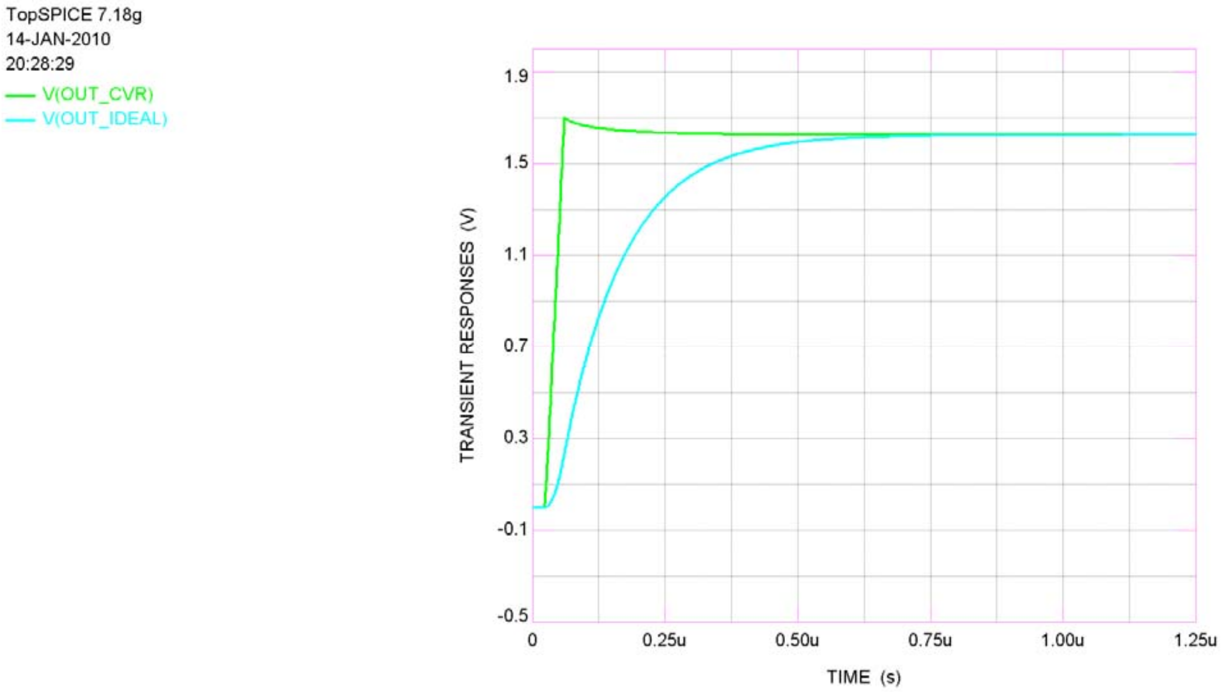

Figure 3. Voltage across the CVR (V(CVR_OUT)) and voltage across the *Rcvr* (V(CVR_IDEAL)). For the case where the L/R of the source is equal to that of the CVR (risetime portion of the pulse).

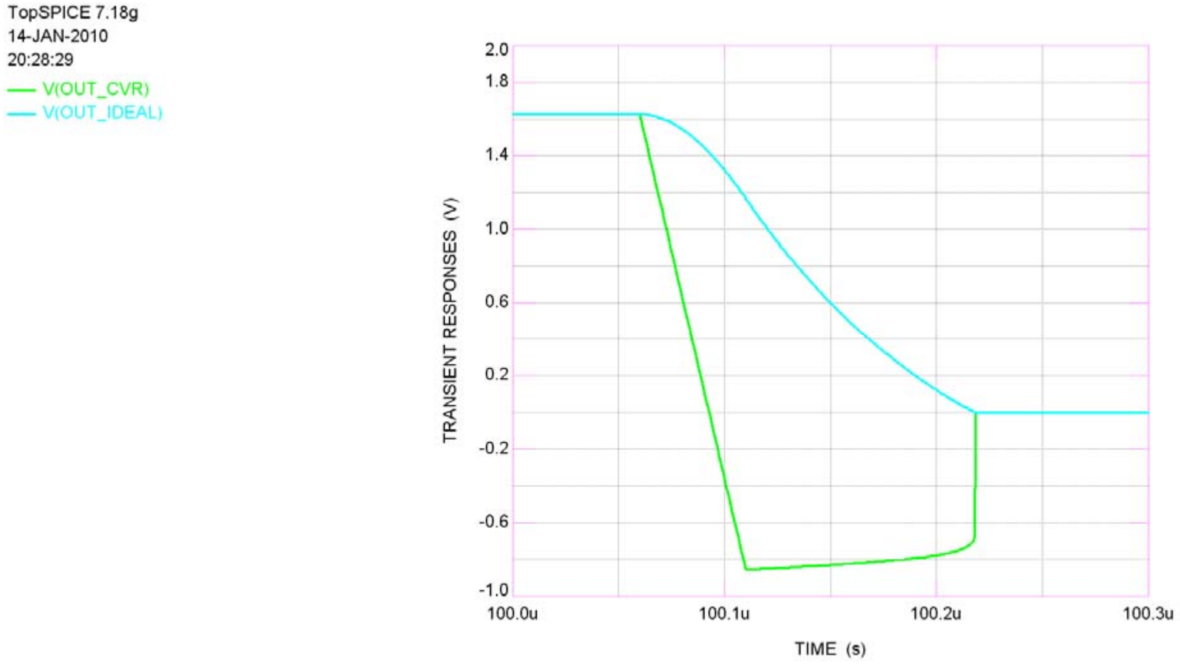

Figure 4. Voltage across the CVR (V(CVR_OUT)) and voltage across the *Rcvr* (V(CVR_IDEAL)). For the case where the L/R of the source is equal to that of the CVR (falltime portion of the pulse). Notice the significant undershoot in the CVR voltage which is not present in the actual laser diode current.

The error in the CVR voltage can be eliminated by compensating for the single pole in the CVR frequency response. Figure 5 shows the frequency response of the 10 mOhm, 1206 surface mount resistor. At low frequency the impedance of the CVR looks purely resistive. As the frequency is increased the impedance of the CVR increases due to its parasitic inductance. If the frequency components of the current rise and fall time are below the 3 dB point, which is 1.3 MHz, minimal distortion will appear in the voltage measured across the CVR. However, if the current risetime is less than ~270 ns, then the measured output of the CVR will not be a true representation of the current flowing through the laser diode.

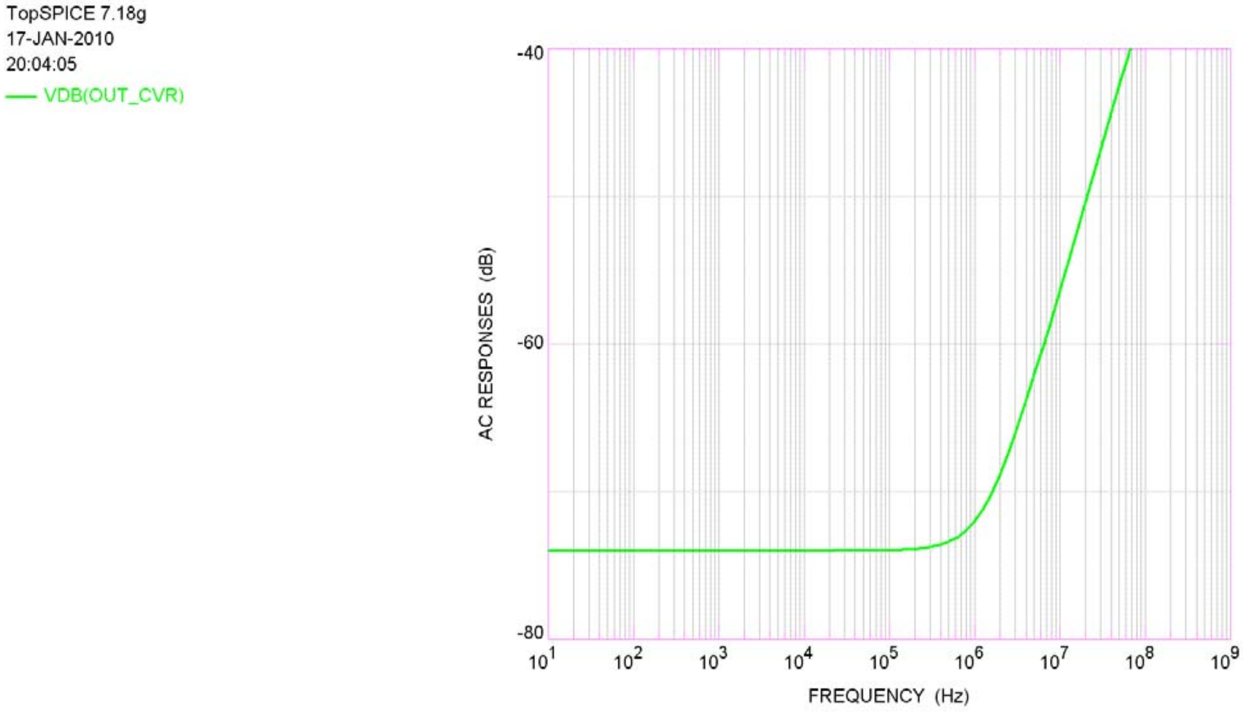

Figure 5. Frequency response of a 10 mOhm, 1206 surface mount resistor with 1.2 nH of parasitic inductance. The 3db point is at 1.3 MHz.

The effect of the parasitic inductance can be annulled by adding a capacitor and resistor to the current sensing circuit (see Figure 6). The simulated waveforms for the circuit shown in Figure 6 are given in Figure 7 and Figure 8. The voltage measured at the output of the compensation capacitor (V(OUT_COMP)) is a true representation of the current flowing through the laser diode (V(OUT_IDEAL)).

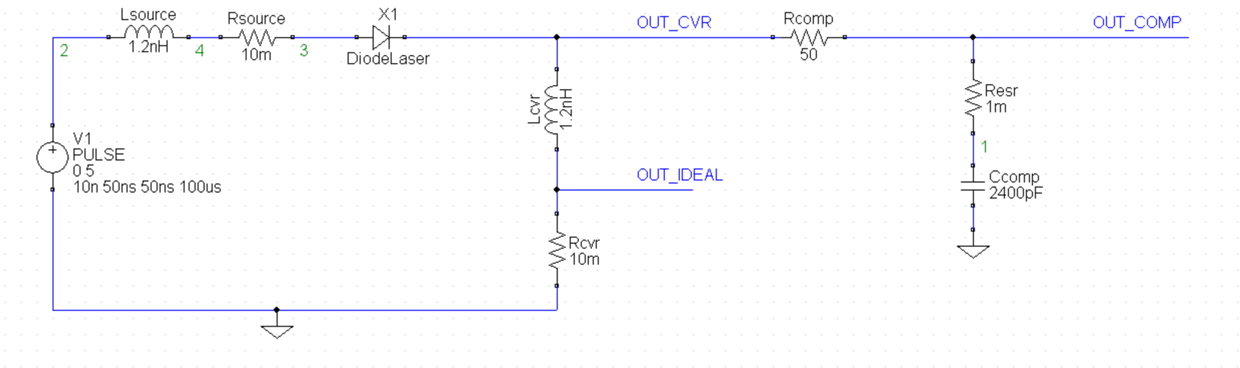

Figure 6. **Schematic of a laser diode driver now incorporating a compensation circuit represented by *Rcomp* and *Ccomp*. *Resr* represents the resistance of the capacitor. By picking *Rcomp*Comp=Lcvr/Rcvr* a flat response in frequency is achieved resulting in excellent agreement between V(OUT_IDEAL) and V(OUT_COMP).**

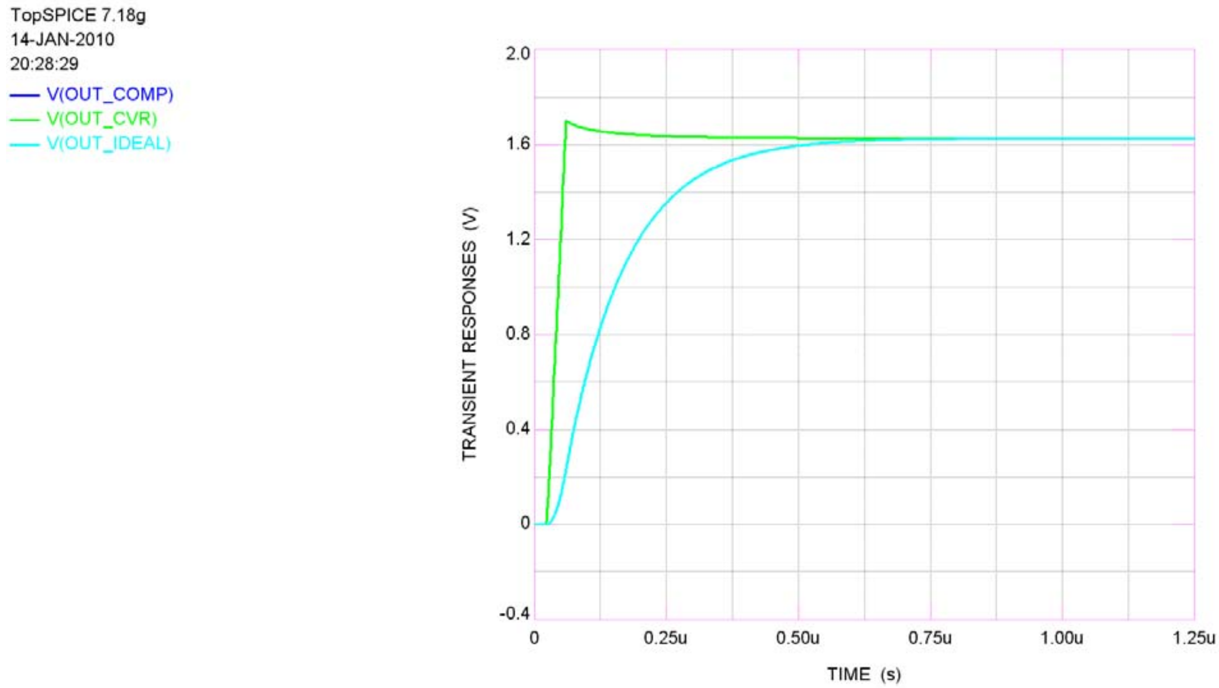

Figure 7. **Voltage across the CVR (V(CVR_OUT)), the voltage across *Rcvr* (V(CVR_IDEAL)) and out of the compensation network (V(OUT_COMP)) for the initial rise-time of the current pulse. The CVR response shows the expected overshoot but V(OUT_COMP) exactly overlays the expected current pulse, V(OUT_IDEAL).**

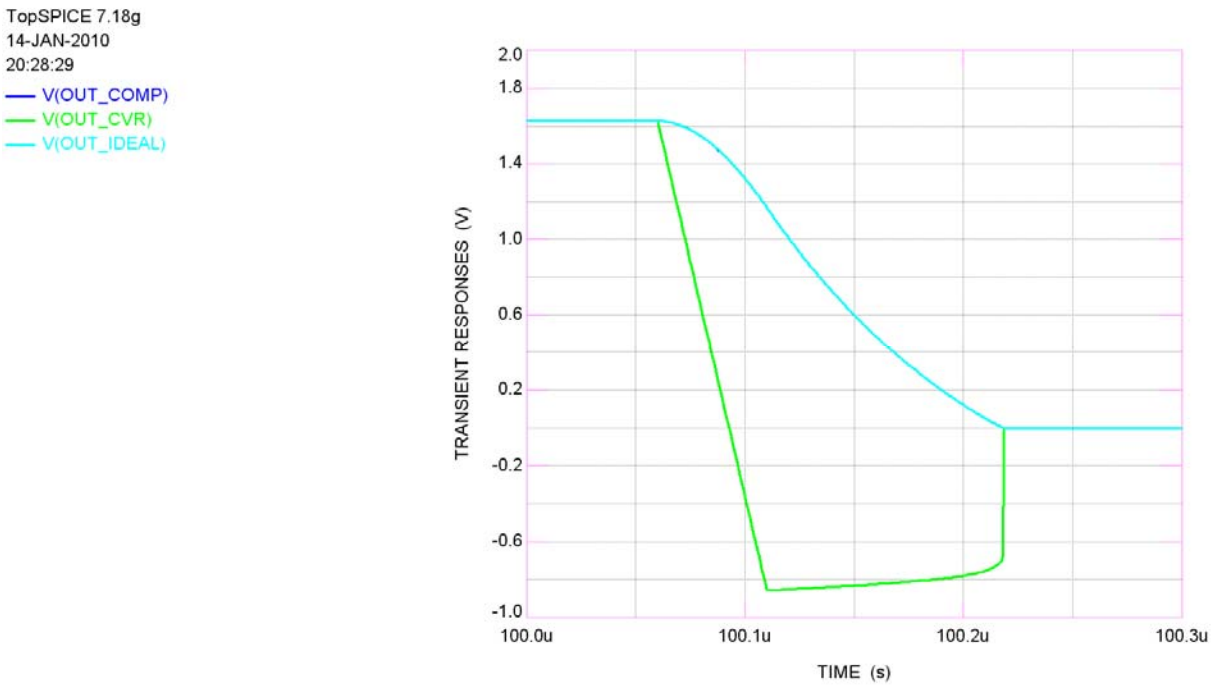

Figure 8. Voltage across the CVR (V(CVR_OUT)), the voltage across the *Rcvr* (V(CVR_IDEAL)) and out of the compensation network (V(OUT_COMP)) for the fall-time of the current pulse. The CVR response shows the expected undershoot but V(OUT_COMP) exactly overlays the expected current pulse, V(OUT_IDEAL).

For a slow risetime circuit obtaining accurate current sensing is not that difficult since the L/R time of the source is typically much longer than the L/R time of the CVR; however, as shown above, even for moderately fast risetime pulses problems can arise. What about for pulses with risetimes of just a few nanoseconds? For this case using only a single 1206 resistor is not going to work. Paralleling higher value resistors is an option, as that reduces the L/R time of the CVR. For example, to make a 10 mOhm CVR you could parallel ten 100 mOhm resistors which would reduce the L/R time to 12ns. This is close to what is needed, but in this game close is not enough, because the L/R time of the CVR must be at least ten times less than the risetime of the circuit. The only other option is to increase the value of the CVR and suffer the power loss. Paralleling ten 10 Ohm resistors to make a 1 Ohm CVR reduces the L/R time to 120 ps and additional reduction can be achieved by using lower inductance 0603 resistors. Using a higher resistance CVR presents another problem because the voltage across the CVR can sometimes exceed the rating of the resistor. For example, if the CVR is 1 Ohm and the pulsed current is 50 Amps then 50 Volts is developed across the CVR. Even if the CVR can handle a high voltage pulse, the designer still needs to worry about making a wide bandwidth, 10:1 or greater attenuator so that the voltage level is compatible with common test equipment.

All of these issues had to be addressed in our PLDD-50-SP which is a high current (50 Amps) short pulse (5ns) driver. The PLDD-50-SP can drive a variety of laser diodes and the current monitoring circuit has been designed and validated using a network analyzer for flat response beyond 1 GHz. To demonstrate the accuracy of the current monitor we integrated a Laser Components laser diode (905D1S16U) onto the output pads of the PLDD-50-SP. Figure 9 shows the current monitor output of the PLDD-50-SP (Ch1) and the output of the photodetector (Ch2). The photodetector was a Precision Applied Sciences Model PD1000 that has a 250 ps risetime. The agreement between the two signals is excellent.

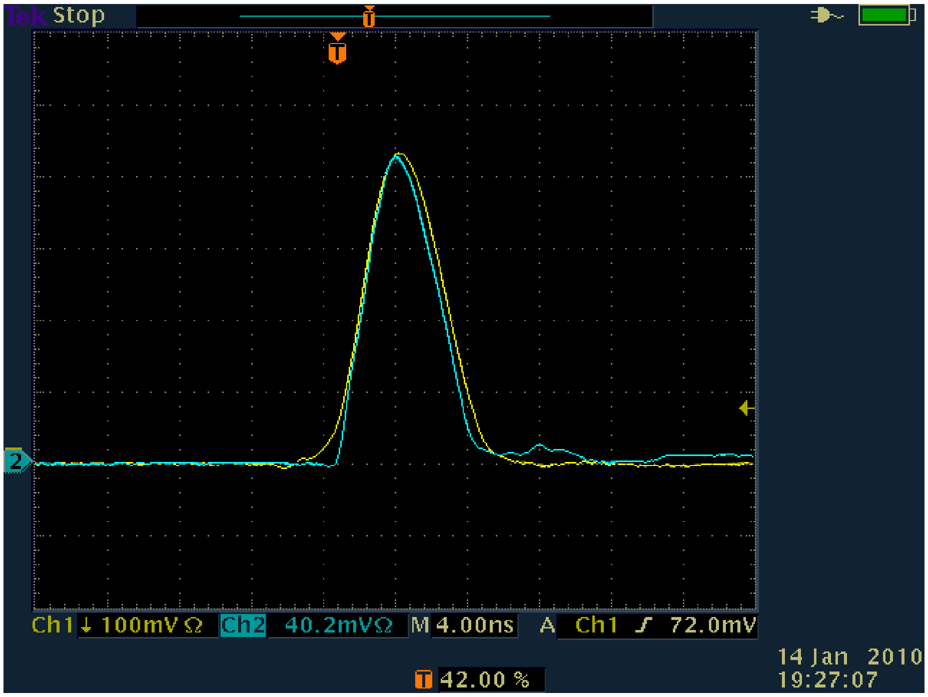

Figure 9. Current monitor output of the PLDD-50-SP (Ch1) and the output of a photodetector (Ch2). 4ns/div (averaged)

Conclusion

When driving pulsed laser diodes it is essential to know the magnitude and the shape of the current through the laser diode. Using an output signal from a photodetector to represent laser diode current can make a poorly behaved driver appear to operate better than it actually does. Considering the factors involved in creating an accurate current monitor, the most straightforward method to obtain meaningful and true data is with a properly designed current monitor integrated with the laser diode driver. There is no magic in building an accurate current monitor, but it does require precise modeling of all the parasitic elements and validation for flat response in the frequency domain using a network analyzer.