Laser Diode System Design Considerations for Modulation at Greater Than 10 Amps

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ABSTRACT

Operation of a laser diode, a laser diode driver, and a power supply at high currents and high modulation frequencies introduces technical difficulties that may not appear when operating under less demanding conditions. The latent electronic limitations become a dominant factor in performance. Without special care, the system as a whole can see degraded performance. To avoid this degradation, high current operation (greater than 10 A), with a square wave modulation waveform will be considered. Technical difficulties will be explored, solutions will be presented, and suggestions for choosing a well-suited power supply will be discussed.

MODULATION & HIGH CURRENT

Modulation of a semiconductor laser's injection current has practical uses such as pulsing and sweeping the frequency of the laser output. Modulating with high currents (greater than 10 A) at high frequency (hundreds of kilohertz and above) magnifies underlying issues that are often suppressed at lower currents and/or lower frequency.

All wires, printed circuit board (PCB) traces, and connection terminals have some non-zero resistance. As the current levels rise, the voltage drops throughout these portions of the circuit rise as well, dictated by Ohm's Law. Minimizing these voltage drops increases stability.

Modulation amplifies difficulties involving inductance and feedback control. Inductance can reduce signal integrity due to its opposition to changes in the current. The rate of change of current impacts the ability for the driver to maintain precision current control. Wavelength Electronics laser diode drivers utilize feedback to output the desired current, and are thus bound by feedback control theory and subject to all of the real-world caveats.

Designing precision laser diode driver systems requires knowledge of the physical circuit connections. An understanding of the voltage drops due to wiring (resistance), opposition to modulation (inductance), and reduction of signal integrity (bandwidth) is key to optimized performance. At high frequency/high current, each becomes more critical to system design.

Additionally, the power supply can have difficulty maintaining a stable output voltage. At high frequencies, especially when dealing with square waves, the voltage output can droop as the load changes when the pulse edges are propagating through the system. This deviation gets larger when operating at higher currents, and is maximized when the modulation involves the output going from totally off (0 A) to fully on.

RELATIONSHIP BETWEEN POWER SUPPLIES AND LASER DIODE DRIVERS

Wavelength Electronics OEM laser diode drivers (LDD) are voltage-controlled current sources, and require separate power supplies for operation. The user sets operational parameters on the LDD, which is connected to the power supply. The power supply will attempt to output a specific voltage (model-dependent), along with the current that the LDD requires[a].

When modulation occurs, the LDD draws different current levels from the power supply as the modulation waveform passes through the system. If the modulation is too fast, or too large, the power supply can become the limiting factor of the system.

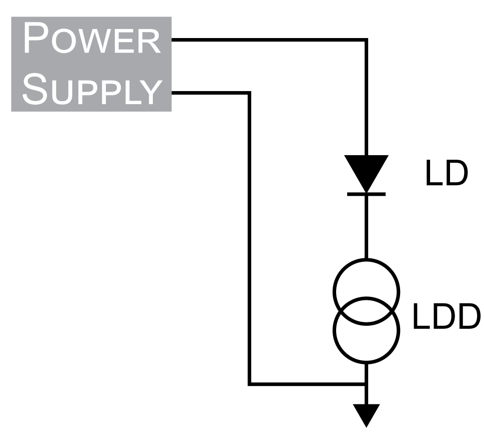

Figure 1. Example schematic of a power supply (in shaded gray box), a laser diode (LD) and a laser diode driver (LDD).

[a] For more information on Laser Diode Drivers, see *AN-LD13: Laser Diode Driver Basics*.

LDD DESIGN FACTORS: RESISTANCE & INDUCTANCE

Square wave modulation is commonly used to effectively pulse the output of a laser, an example is given below in **Figure 2**.

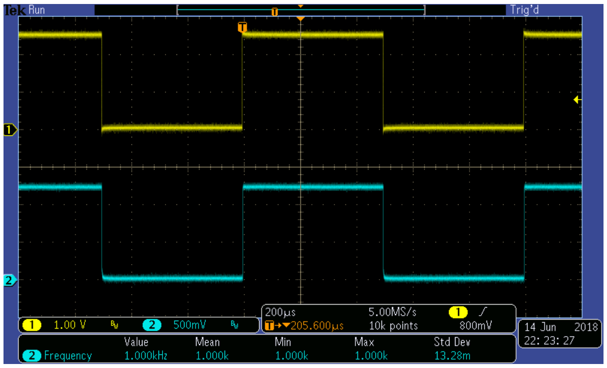

Figure 2. 1 kHz square wave modulation waveform (yellow, top trace) and the resulting driver output (blue, bottom trace).

PROBLEM

Square wave modulation exacerbates the technical difficulties discussed here, due to the high rate of change in current encountered at the pulse edges. The inherent inductance in all wires resists changes to the current. This can be seen in Eq. (1) for the voltage V_L across an inductor,

$$V_L = L(dI/dt)\ , \qquad \textbf{(1)}$$

where *L* is the inductance, *dI/dt* is the derivative of the current with respect to time.

At the pulse edges, the rate of change in current with respect to time is maximized. Additionally, the rising/falling of the pulse is intended to be as short as possible. As such, any inductance present (either an inductor, or parasitic inductance) is going to oppose the modulation–the more current and the faster the modulation, the greater this opposition.

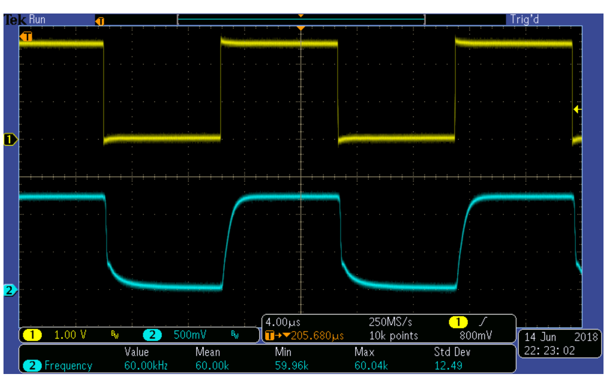

Figure 3. Driver response to a 60 kHz square wave. Note the output's rounded corners (blue/bottom trace).

SOLUTION – PROPER WIRE CHOICE

The physical characteristics of the wires determine the voltage drop along the length of the wire. Proper wire choice minimizes the resistance and the inductance, both of which lead to voltage drops in the system.

Choose the shortest and heaviest gauge wires possible for the application at hand. The inductance of a wire [1] is directly proportional to the length of the wire and inversely proportional to the radius of the wire,

$$L \sim \ell[\ln(\ell/r)]\ , \qquad \textbf{(2)}$$

where *L* is again the inductance, ℓ is the length of the wire, ln is the natural logarithm, and *r* is the radius of the wire.

Thus, Eq. (2) presents two methods of reducing the inductance present in the wires. First, make all the wires as short as possible. Inductance increases with length. Second, use the largest diameter wires possible. Inductance decreases as the diameter increases.

An added benefit of the short, heavy gauge wires is that the resistance (*R*) also becomes minimized under these conditions. Resistance of a wire[b] is defined [2,3] as

$$R = \rho(\ell/A)\ , \qquad \textbf{(3)}$$

where ρ is the given resistivity of the material, ℓ is again the length of the wire, and *A* is the cross-sectional area of the wire. Eq. (3) can also be applied to traces on PCBs.

The consequences of poor wire choice may not always present themselves obviously on an oscilloscope screen. Depending on the wire choice and operational parameters, this may be one of the more hidden detractors from optimal performance. For example, during testing, switching from 6 inches of 16 AWG wire to 3 feet of 24 AWG wire made a negative difference in the response to a square wave. While not glaringly obvious, under careful observation, it was noticed that the response to the step had become underdamped due to the change of wires.

[b] Assuming uniform cross-section and uniform current.

LDD DESIGN FACTOR: BANDWIDTH

If the effective modulation bandwidth of the system is exceeded, the resulting output from the driver will begin to deviate from the desired waveform. Frequency increases cause the driver to lose the ability to suppress errors, and the inherent gain present in the output stage decreases, both of which can cause the waveform to change. Two examples of waveform deformation are presented here, one for a square wave, and another for a sine wave modulation waveform.

SQUARE WAVE

As discussed previously, square wave modulation is the most taxing form of modulation, due to the rapid rates of change present at the pulse edges.

The output signal reflects the difficulty that the system has with this type of modulation once the effective range has been exceeded. The desired square wave becomes morphed into something that has no definitive sharp edges, and cannot be changed from minimum to maximum as sharply as desired. **Figure 4** illustrates what might be seen if the bandwidth of the driver is exceeded by the frequency of the signal from the function generator.

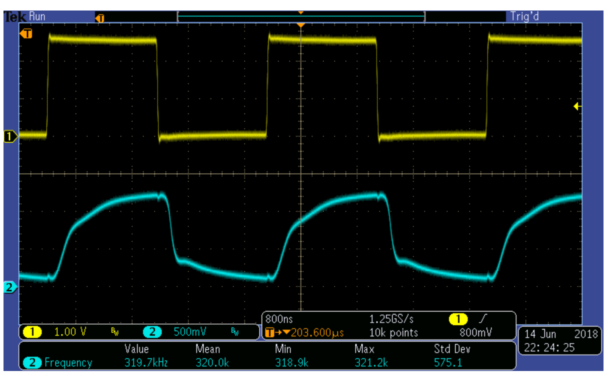

Figure 4. The system response (blue, bottom) cannot adequately maintain the desired waveform output (yellow, top) if the frequency of the waveform is greater than the effective bandwidth of the system. Here, the input frequency is less than 25 Hz above the specified maximum bandwidth.

Mathematically, square waves can be described by an infinite series of a sine wave and its odd harmonics. As the harmonics increase, the frequency also increases. The combination of high frequency harmonics contributes to the modulation bandwidth being exceeded. **Figure 5** shows how multiple harmonics summed together forms square waves, along with the infinite series representation of a square wave.

$$x(t) = \frac{4}{\pi} \sum_{n=1}^{\infty} \frac{\sin[2\pi(2n-1)ft]}{2n-1}$$

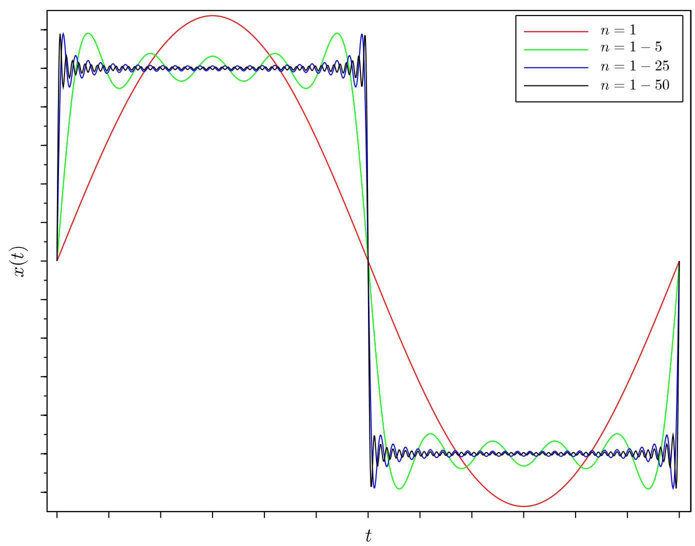

Figure 5. Mathematical model of the formation of a square wave using a sine wave and higher-order odd harmonics. The equation above the plot shows the formulation used.

SINE WAVE

Sine waves are less taxing on the driver than square waves, due to the lack of sharp edges and higher frequency harmonics in the waveform. As such, the results of exceeding the bandwidth are less jagged than the previous example of a square wave.

Figure 6 shows the result of exceeding the driver's specified bandwidth with a sine wave. Instead of sharp, jagged deviations, the resulting output is skewed and shifted as the driver struggles to keep up with the function generator.

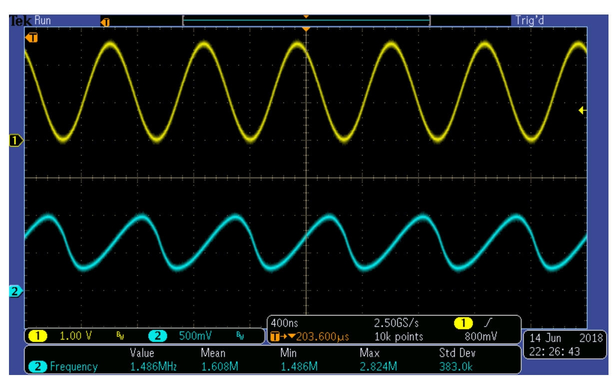

Figure 6. At nearly triple the specified 3 dB bandwidth of the driver, the resulting output sine wave (blue, bottom) is visibly distorted from the desired modulation (yellow, top).

POWER SUPPLY DESIGN FACTORS: FEEDBACK LIMITATIONS, PARASITIC IMPEDANCES & STEP RESPONSE

When operating electronics at high frequencies, deviation from linear operation can be encountered. If this occurs, the system will perform sub-optimally. It may lose its ability to suppress errors, or may not be able to output the required current/voltage.

PROBLEM

Rise and fall times that are faster than the feedback response of the power supply lead to transient events in the output of the power supply, where the voltage output from the power supply deviates from a constant value. An example of this deviation can be seen in the bottom trace of **Figure 7**.

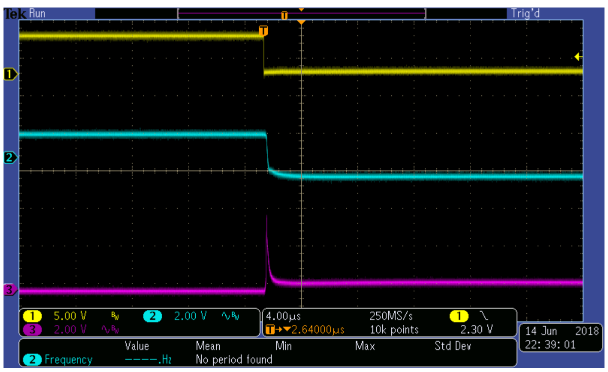

Figure 7. Stability of power supply output can be reduced with a pulsed waveform. The input from the function generator (yellow, top) results in output current from the driver (blue, middle), with power supply response (magenta, bottom) that deviates from constant at the sharp edge of the modulation waveform.

SOLUTION – CAPACITOR BANKS

Introducing a capacitor bank into the system will reduce some of the stress on the power supply. The capacitors, due to their low impedance at high frequencies, aid in minimizing the deviations from constant output voltage at abrupt current changes. This method allows the power supply a more lenient time response to changes in the current requested. The capacitor bank will effectively handle short-term changes that the power supply cannot keep up with (for example, steps in the output current), while the power supply itself will attempt to maintain a long-term steady voltage [4]. See **Figure 8** for a schematic representation of a capacitor bank implementation.

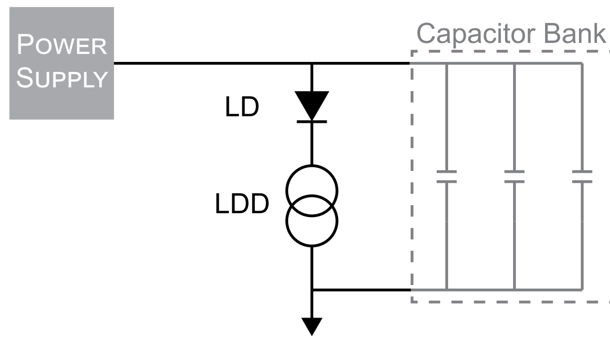

Figure 8. A capacitor bank (within the dashed box) can improve power supply output voltage stability.

Another added benefit of the capacitor bank with multiple capacitors is that the parasitic resistance that is present in the wires will be reduced when the wires are put in parallel, reducing the overall equivalent series resistance (ESR) of the capacitor bank. Low ESR reduces the voltage drop through each wire that can lead to inconsistencies in voltage output to the laser diode driver. Consistent voltage output regardless of the load requirements is specified as "load regulation" and is discussed further on **page 5**.

When considering implementation of a capacitor bank, it is important to choose capacitors with both low ESR, and low equivalent series inductance (ESL). This will keep the overall impedance low at high frequency operation.

POWER SUPPLY DESIGN FACTORS: CHOOSING THE RIGHT POWER SUPPLY

Power supply choice is critical in reaching optimal system performance when operating at high currents and high modulation frequencies. There are certain parameters and operating conditions that can aid in maximizing power supply performance under these conditions.

SLOW-START

A power supply equipped with a slow-start feature (or manually implemented by the user) has multiple advantages. A power supply, when enabled, wants to output a specific voltage right away. By either utilizing the slow-start feature, or setting the voltage to a low value and slowly increasing the voltage output, the stress on the power supply can be reduced significantly. As seen by the capacitance equation,

$$I = C(dV/dt), \qquad \textbf{(4)}$$

the current that is output by the power supply depends on the change in voltage with respect to time. If the *dV* is too large (or the *dt* is too small), the stress on the power supply may cause it to fail.

NOISE & RIPPLE

Noise & Ripple is an important specification when choosing a power supply. As explained in the section **Relationship Between Power Supplies and Laser Diode Drivers**, the laser diode driver has no control over the voltage being supplied to it from the power supply. This means that, from the viewpoint of the driver, the power supply is part of the signal path.

In terms of stability, the driver cannot distinguish what part of the voltage output is desirable, and which part of the voltage output is "noise." The noise that is output from the power supply induces noise in the current output of the driver.

Choose a power supply with appropriate specifications for the desired application that has the lowest Noise & Ripple for optimal performance.

REMOTE SENSING LEADS

Power supplies equipped with remote sensing leads are an ideal choice for the operating conditions discussed here. They allow the power supply control to bypass some of the inherent inductance and parasitic resistance that are internal to the power supply and connecting wires.

The remote sensing leads measure the voltage at a location external to the power supply, as opposed to an internally monitored value (see **Figure 9**). This allows the power supply to attempt to maintain a more accurate output voltage, compensating for losses in the wiring.

For example, remote sensing leads can be used to sense the voltage that is at the load (see point *B* in **Figure 9**). Sensing the voltage at the load has multiple advantages. First, the voltage that is sensed and used as feedback is more meaningful, as it is located where the voltage is intended to be at the set value. Secondly, as seen by Eq. (2) and (3), the inductance and resistance are functions of length. The connection wire from the power supply to the load has some length, and by sensing at the load, those losses are taken into account.

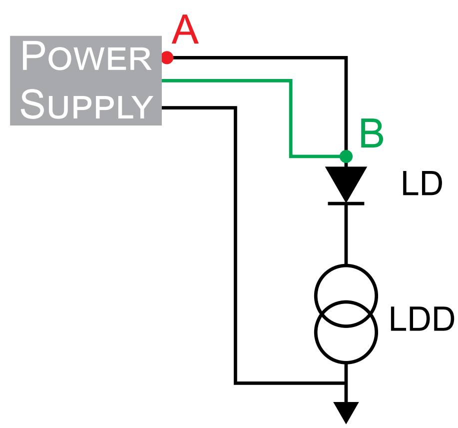

Figure 9. Schematic showing implementation of remote sensing leads. Power supplies not equipped with remote sensing leads will measure the output voltage at point *A*, while remote sensing leads will measure the output voltage at point *B*, leading to more accurate voltage to the load.

LOAD REGULATION

The ability for power supplies to output constant voltage without regard to the variations in the load is known as load regulation. Power supplies with better noise specifications, and remote sensing leads, among other features, will have superior load regulation.

The ability for a laser diode driver to supply low-noise current is dependent on consistent voltage from the power supply. High-level load regulation is required for this.

SUMMARY

Operation of a laser diode system at high currents and high frequency mandates that special attention be paid to layout and electronic setup. Inductance, capacitance, and impedance play crucial roles in system performance when operating under these conditions.

The two simplest solutions are often the least desirable, as they change the operating conditions. They involve 1) lowering the operating current and 2) lowering the frequency of the modulation. All of the issues described are exacerbated when operating at high currents with high modulation frequencies. By lowering the operating current and/or lowering the modulation frequency, the negative effects will be significantly lessened.

There are additional solutions that do not require the modification of operational parameters. The choice of wires used for connections, the introduction of capacitor banks, and proper power supply selection can lead to significant improvements in performance of high current and high frequency operation.

By choosing short, large diameter wires, the inductance and parasitic resistance are reduced in the system wiring. This leads to less voltage being lost in the wires, making it easier for the power supply to maintain a stable voltage.

Capacitor banks allow for the power supply to have less stringent time-response parameters, with the capacitors providing short term stability at pulse edges. The additional stability provided in the short term by the capacitors enables better long term stability from the power supply.

A high quality power supply with slow start capability, remote sensing leads, low Noise & Ripple and load regulation specifications is ideal for situations described here. The slow start feature reduces the strain upon power up, the remote sensing leads enhance the voltage accuracy, and low Noise & Ripple along with good load reguation enables more stable voltage output to the driver.

REFERENCE

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2. E. Bogatin, *Signal Integrity – Simplified* (Prentice Hall, 2004), Chap. 4.
3. D. J. Griffiths, *Introduction to Electrodynamics – 4th Edition* (Cambridge University Press, 2017), Chap. 7.
4. P. Horowitz and W. Hill, *The Art of Electronics – 3rd Edition* (Cambridge University Press, 2015), Chap. 9.

USEFUL LINKS

- *AN-LD13: Laser Diode Driver Basics*
- *AN-LDTC03: Power Supply Basics*

KEYWORDS

power supply, laser diode driver, modulation, bandwidth, resistance, capacitance, inductance, impedance, frequency, step response, rise time, fall time, feedback, control theory

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A	September 2018	Initial Release