Achieving nanosecond-level precision laser pulse control for lidar and ToF systems

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Introduction

The growing adoption of autonomous vehicles, industrial automation and advanced robotics is increasing demand for reliable 3D ranging and sensing. Lidar and time-of-flight (ToF) systems rely on precisely controlled laser pulses to measure distance and spatial information. Meeting these requirements demands laser drivers that deliver high peak current and maintain pulse-to-pulse stability across temperature and aging. Whether used for navigation or high-speed industrial inspection, these systems depend on fast, stable and repeatable laser pulses under practical conditions. Traditional discrete topologies that use gate drivers, external field-effect transistors, and current-sensing elements can meet specific design requirements; however, they often introduce trade-offs in terms of layout complexity, calibration effort, and thermal performance.

What makes laser pulse control challenging?

Laser drivers do more than deliver current. They directly influence the timing information that lidar and ToF systems use to calculate distance. Consider a simple timing variation budget comprising of several sources, where for the purposes of this article there are three contributors:

- Rise and fall time ($t_{r/f}$): how quickly the pulse moves through the detection threshold.
- Propagation delay (t_{pd}): how long it takes from the trigger to actual light emission.
- Pulse-to-pulse variation (t_{pp}): how much the timing or amplitude drifts from pulse to pulse.

Effects of rise and fall times

Lidar and ToF systems measure the distance by calculating the round-trip time for a laser pulse to travel to a target and return to a receiver. The ability to distinguish small distance changes depends on how quickly the pulse edges transition between no light and full light. Faster rise and fall times reduce distance uncertainty and give the receiver a clearer reference point. In high-resolution systems, rise and fall times typically range from 1ns to 5ns.

When a pulse edge is slow, the system cannot determine the exact moment the signal crosses the receiver detection threshold. A $t_{r/f}$ equal to a 1ns edge therefore introduces about 150mm of distance uncertainty, approximated by **Equation 1**:

$$\Delta D = \frac{ct_{r/f}}{2} \tag{1}$$

where ΔD is the delta distance and $c \approx 3 \times 10^8$m/s.

This uncertainty increases with slower pulse edges, which parasitics such as package and printed circuit board (PCB) inductance can limit, along with the capacitance of the laser diode and driver output. For example, increasing $t_{r/f}$ from 500ps to 1ns doubles the distance, while edges of 2ns expand it to nearly

300mm, limiting the system's ability to distinguish smaller differences in target distance then ΔD.

Propagation delay

In high-speed optical systems, every nanosecond matters. If the propagation delay changes with temperature, supply voltage or component tolerances, it shifts the timing reference used for distance calculations and can also disrupt synchronization between channels. In direct ToF applications (dToF), a 100ps variation in t_{pd} corresponds to roughly 30mm of distance error, based on the ToF relationship shown in **Equation 2**:

$$D = c \times t \tag{2}$$

where $c \approx 3 \times 10^8$m/s, D is the distance and t is the time.

Any excess delay directly translates into ranging error. As shown in **Figure 1**, a 500ps variation could result in more than 150mm of round-trip distance error, which is unacceptable in dToF systems targeting centimeter- or millimeter-level accuracy.

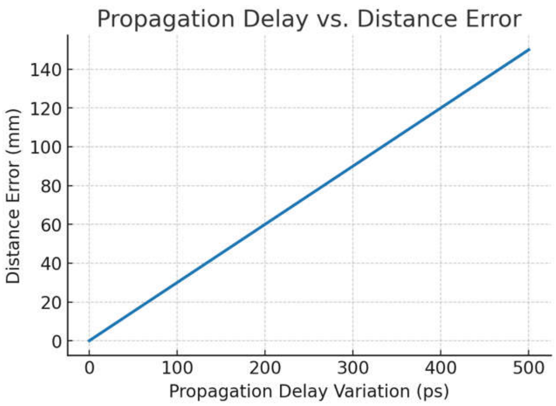

Figure 1. *Propagation delay vs. distance error (estimated)*

It is possible to calibrate fixed delays during system alignment, but variable delays such as self-heating introduce measurement-to-measurement uncertainty that is not easily correctable.

Pulse-to-pulse stability

Even a fast, narrow laser pulse must remain consistent from one pulse to the next. Variations in peak current translate directly into changes in optical power, degrading measurement accuracy and system reliability. Temperature shifts, supply fluctuations and device aging are common sources of this drift.

From a system perspective, the receiver relies on the returned optical signal to determine distance. Differences in pulse strength can therefore be misinterpreted as range variation, particularly at long distances where return signals approach the detection threshold. In threshold-based ranging systems, a 1% change in peak current produces roughly a 1% change in optical power, which can introduce distance errors on the order of tens of centimeters. As shown in **Figure 2**, even modest amplitude variations of ±2% to ±5% can alter the pulse envelope and optical energy delivered per pulse, reducing ranging accuracy and repeatability over time. High-performance designs therefore tightly control the drive current, keeping t_{pp} variation within a few percent across all operating conditions.

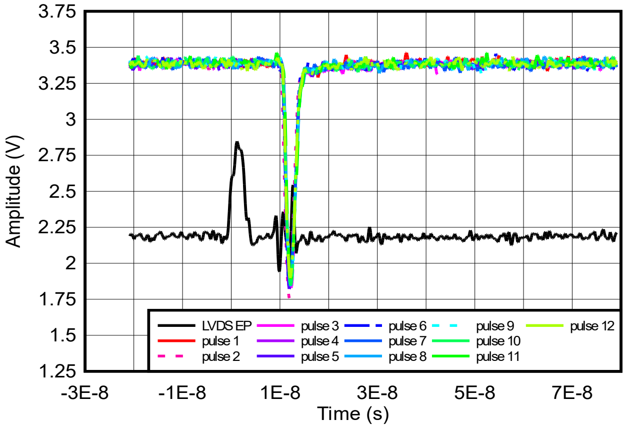

Figure 2. *Pulse-to-pulse amplitude for 12 pulse, 1.5A current, Rdamp =1Ω and 2 snubber pair of 5Ω resistor and 330pF cap, AVDD = PVDD = VLD = 5V*

With the system-level timing constraints defined, the next step is translating them into a practical laser driver implementation.

Implementing precise laser pulse control

Generating accurate laser pulses requires more than delivering current into the diode. The driver must deliver high peak currents with fast edges, predictable delay and repeatable pulse amplitude. TI's LMH13000 high-speed laser driver generates pulses by converting the input voltage at the V_{SET} pin into a precisely regulated sink current at I_{OUT}, as described by **Equation 3**. A digital-to-analog converter (DAC) or reference source sets V_{SET}, while the device's internal current mirror and control circuitry regulate the current through the laser diode, as shown in **Figure 3**. Careful selection of V_{SET}, R_{SET} and the laser anode bias voltage (VLD) allows designers to tune the pulse amplitude, timing and overall pulse stability.

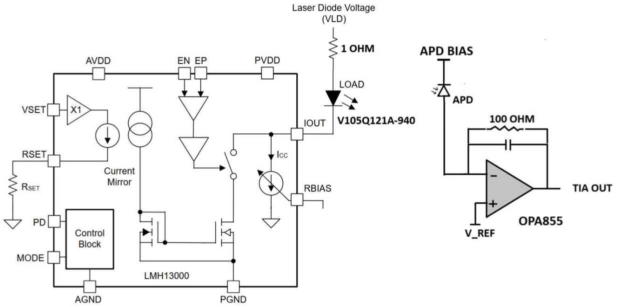

Figure 3. *Circuit schematics transmit path block diagram with a diode and the LMH13000*

Here are the design steps for setting pulse current and speed.

1. Define the target output current (I_{OUT}). Begin with the optical power that the laser diode requires. **Equation 3** expresses the peak output current, set by the laser's slope efficiency:

$$I_{OUT} = \frac{P_{OPT}}{\eta} \quad (3)$$

   where P_{OPT} is the desired optical output power and η is the laser's slope efficiency (watts per ampere). For example, if P_{OPT} = 1W and η = 0.5W/A, then I_{OUT} = 2A.

   Because the LMH13000 supports pulsed currents up to 5A, the selected laser diode must achieve the target optical power at or below this limit. Accurately setting I_{OUT} is paramount for minimizing t_{pp} and reducing amplitude-driven timing errors.

2. Select R_{SET} and V_{SET}. The LMH13000 sets the output current using the ratio of V_{SET} to R_{SET}, scaled by an internal gain factor k (**Equation 4**):

$$I_{OUT} = \frac{V_{SET}}{R_{SET}} \times k \quad (4)$$

   In high-current mode (MODE = 1), k ≈ 50k. For example, with R_{SET} = 20kΩ and V_{SET} = 0.8V:

$$I_{OUT} = \frac{0.8}{20k} \times 50k \approx 2.0A$$

   It is possible to make fine adjustments by trimming V_{SET} with a DAC. Because the LMH13000 regulates current on-chip, this approach minimizes sensitivity to temperature and supply variations, helping keep t_{pp} small within the timing budget.

3. Set the VLD. VLD must be high enough to support the laser forward voltage and dynamic voltage required during fast current transitions. The LMH13000 data sheet provides **Equation 5** as a sizing guideline:

$$VLD = V_{OUT(MIN)} + V_F L \times \frac{dI}{dt} + I_{OUT} \times (R_{LASER} + R_{DAMP}) \quad (5)$$

   where:

   - V_{IOUT} is the minimum compliance voltage at I_{OUT}
   - V_F is the forward voltage of the laser at I_{OUT}
   - L is the total loop inductance (package and PCB)
   - dI/dt is the current slew rate (amperes per second) from rise and fall requirements
   - R_{LASER} is the dynamic resistance of the laser diode
   - R_{DAMP} is the external resistance of the laser diode

For example, with:

$$V_{IOUT(MIN)} = 6V$$

$$V_F = 2V$$

$$L = 3nH$$

$$\frac{dI}{dt} = \frac{2A}{1ns} = 2 \times 109A/s$$

$$R_{LASER} = 0.3\Omega$$

$$R_{DAMP} = 1\Omega$$

$$VLD \approx 6 + 2 + \left(3 \times 10^{-9}\right)\left(2 \times 10^{9}\right) + 2(0.3 + 1.0) \approx 16.6V$$

A starting value of 17V is therefore appropriate. Increasing VLD improves the edge speed but can increase overshoot, thus requiring careful tuning. Proper VLD selection ensures fast transitions while limiting overshoot, directly reducing the rise and fall time ($t_{r/f}$) contribution to the overall total timing variation (t_{total}) budget.

4. Optimize rise and fall times and damping. Both driver capability and circuit parasitics set the rise and fall times. Without proper damping, fast current pulse transitions can excite ringing in the laser and PCB loop, causing overshoot and unstable optical pulses. Designers commonly address this by adding a damping resistor and snubber network at the I_{OUT} node. Together, the resistor and snubber suppress parasitic ringing, preserve fast edges, and prevent $t_{r/f}$ from unnecessarily increasing t_{total}.

   Select snubber capacitors based on the output capacitance of the driver, calculated using **Equation 6**:

   $$C_{SNUB} \approx 5 \times C_{IOUT} \qquad (6)$$

   where C_{IOUT} is the effective capacitance at the I_{OUT} pin. If C_{IOUT} = 40pF, then C_{SNUB} ≈ 200pf.

   Adding a small damping resistor in series with the laser and snubber network suppresses unwanted oscillations. As shown in **Figure 4**, typical values for R_{DAMP} and R_{SNUB} are in the 5Ω to 10Ω range, with the snubber capacitor sized to the output node capacitance. Select C_{SNUB} for the worst-case (highest) C_{IOUT}, trimming during validation to balance overshoot and edge speed. As illustrated in **Figure 5**, this approach reduces ringing from fast transitions and PCB parasitics, while preserving the sub-nanosecond $t_{r/f}$ required for precise pulse control.

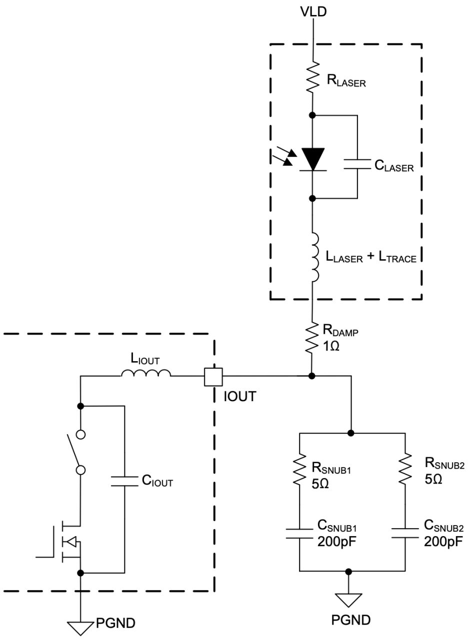

Figure 4. *Damping resistor and snubber network circuit*

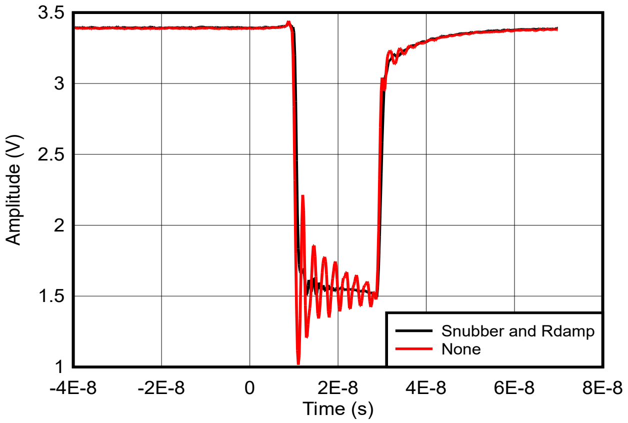

Figure 5. *The LMH13000 pulse with and without a snubber circuit or R_{DAMP}*

5. Control the propagation delay. Unlike rise and fall times, propagation delay is not defined by a formula

but instead depends on these layout and interface practices:

- Input routing. Use differential routing for EP pin and EN pin with 100Ω termination, or route a single-ended input with controlled impedance and proper termination at the LMH13000 input.
- Output loop. Keep the high-current I_{OUT} loop short and tightly coupled to PGND to minimize inductive delay and ringing.
- System calibration. Account for any residual system delay by including the driver-laser path in the ToF measurement budget.

As shown in **Figure 6**, minimizing the trace inductance and ensuring consistent input termination reduces variation in t_{pd}, keeping this contribution small and predictable. For applications that require even higher accuracy or where temperature-based calibration is not practical, Section 6.3.2 of the **LMH13000 datasheet** presents a technique for high-accuracy start-pulse generation by directly monitoring the laser stage.

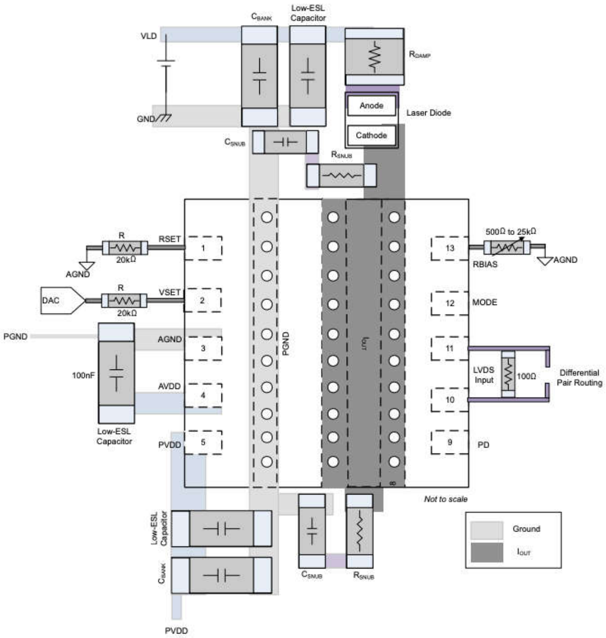

__Figure 6.__ Layout example of the LMH13000 in the surface-mount device package

Precise pulse control in pulsed systems

Lidar and ToF systems typically operate in pulsed mode, generating high-current bursts separated by long off-times. In this mode, the current waveform must settle quickly and reach the same peak value on every pulse. A common approach is to pre-bias the laser anode through VLD and use the LMH13000's low-voltage differential signaling (LVDS) inputs (EP, EN) to gate the pulses. This enables V_{SET} pin to set the amplitude while the LVDS inputs independently control the timing.

With R_{DAMP} = 2.6Ω, VLD = 12V and I_{OUT} = 400mA (laser diode: Osram's PLT5 518FB_P), **Figure 7** shows the lab result with a laser diode. In the figure, blue is enable, yellow is the start pulse and orange is V_{ANODE}. Decoupling amplitude and timing minimizes pulse-to-pulse drift and preserves fast edges, improving both amplitude stability (t_{pp}) and edge consistency ($t_{r/f}$), further lowering t_{total}.

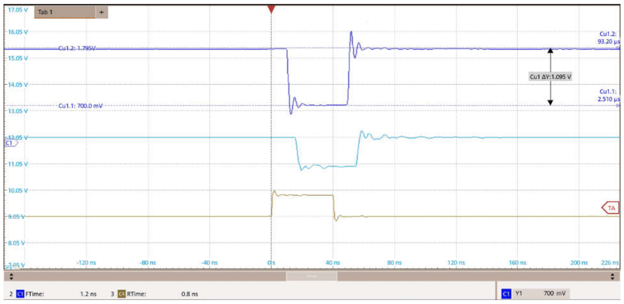

__Figure 7.__ Precise pulse control in pulsed mode

Practical example with transmitter test results

Testing the LMH13000 under the lidar transmitter conditions shown in **Table 1** validates the design principles.

Design parameters	Value
Diode	V105Q121A-940
Analog VDD and power VDD	5V
Mode	1
Pulse current	2A peak
Pulse width	0.6ns, 0.7ns
R_{SET}	20kΩ
V_{SET}	0.5V (set by the DAC)
VLD	4.5V, 5V, 6.5V

Design parameters	Value
Damping network	R_{DAMP} = 1Ω R_{SNUB} = N/A C_{SNUB} = N/A (no snubber)

Table 1. *Design parameters for LMH13000 pulse driver example*

Figure 3 shows the test setup, which illustrates the circuit schematic used to bias the laser and configure the LMH13000.

Figure 8 shows the optical response of the LMH13000 at different VLD bias voltages during pulsed operation. The transient waveforms illustrate how VLD directly affects rise times, overshoot and steady-state current regulation. A lower VLD results in slower edge transitions, while a higher VLD improves speed but may increase overshoot. Selecting the appropriate VLD, therefore, balances $t_{r/f}$ against pulse stability to minimize its contribution to the overall variation budget.

This design demonstrates how careful biasing and damping produce fast, stable optical pulses with minimal overshoot and repeatable performance. Based on the variation budget, this design achieves $t_{r/f}$ <1ns, t_{pd} variation <50ps, and t_{pp} <2%. Together, these results yield a t_{total} well below 1ns, enabling millimeter-level range precision. Additional improvement is possible by incorporating a temperature sensor to compensate for delay drift and amplitude shifts in real time, further reducing environmental contributions to the variation budget.

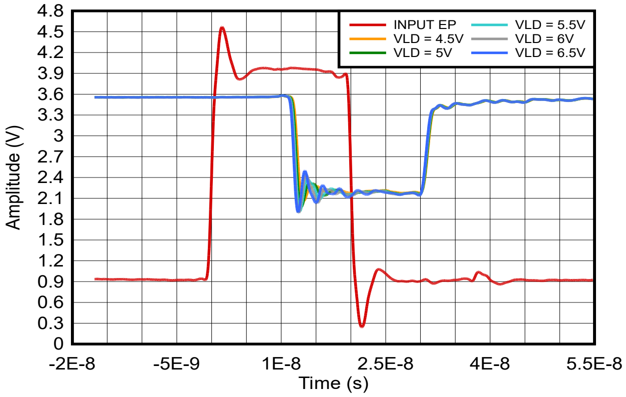

Figure 8. *Optical response at a 4.5, 5, 5.5, 6 and 6.5 VLD bias voltage*

Conclusion

Precise laser pulse control requires balancing edge speed, timing accuracy, stability and optical power consistency. By integrating high-speed current drive and regulation into a compact solution, the LMH13000 reduces design complexity while improving repeatability and performance.

When combined with simple feedback and temperature monitoring techniques, this laser driver provides a reliable platform for both continuous and pulsed laser operation, enabling reliable and accurate performance in demanding lidar, ToF and industrial optical sensing applications.

Additional resources

- Read the application brief, **Automatic Power Control for Laser Diodes Using LMH13000**.
- Check out the white paper, **An Introduction to Automotive Lidar**.
- Download the **LMH13000 TINA-TI™ software Spice model**.

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