An Introduction to Pulsed-Current Laser Diode Drivers

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General

If you are confused by pulsed laser diode specifications, not sure what kind you need, or not an electrical engineer, fear not! This article will help you understand pulsed-current laser diode drivers and choose the right one for your application.

What we do

DEI Scientific by IXYS Colorado designs, manufactures, and markets *pulsers* – devices that deliver electrical pulses for which either the current or the voltage is controlled. They are available in various packages, including boards, modules, and rackmount and tabletop instruments. Select models offer such features as color touchscreens, keypads, and remote computer control.

What is a pulsed-current driver?

For the purposes of this discussion, we define a *pulsed-current driver* as an electronic module or instrument that generates *constant-current* pulses. (A *voltage pulser*, which generates *constant-voltage* pulses, is discussed in another paper.) A current pulser is often used to drive a current-operated semiconductor such as a laser diode or LED.

How’s that again?

It may seem strange to refer to “current pulsers” and “voltage pulsers” when all pulsers involve both current and voltage.

To explain, Ohm’s Law states that current I is proportional to voltage V and inversely proportional to resistance R:

$$I = \frac{V}{R}. \tag{1}$$

So, if the load resistance is fixed, you can set the current or the voltage, but you cannot independently set both the current and the voltage.

In a pulsed-current driver, the output current is the variable that is programmed and controlled. It has no adjustment for output voltage because the voltage depends upon the load. (However, a current pulser may have an upper voltage limit adjustment or some other type of overload protection.)

We use Ohm's Law when talking about resistive loads, but as seen further down, we must also consider the effects of inductance in pulser applications.

What are pulsed-current drivers used for?

DEI Scientific offers various models with outputs from 1 mA to 600 A that are predominantly used to drive, test, and characterize laser diodes and LEDs. If your application involves testing insulation/dielectric materials or driving deflection plates, piezoelectric transducers, or other high-impedance loads, please refer to the DEI Scientific line of voltage pulsers.

How do they work?

A basic pulsed-current driver consists of:

- A fast electronic switch that creates the pulses
- An energy storage system that supplies the peak pulse current required
- A logic-level trigger input that controls the width and repetition rate of the pulses

A more integrated driver may add:

- An internal *pulse engine* that generates trigger pulses
- A current monitor that facilitates viewing the pulse on an oscilloscope
- A power supply that keeps the energy storage system charged

In short, pulsed-current drivers accept energy from a power supply, store it in capacitors or inductors, and then release it in constant-current pulses that follow the trigger input.

Datasheet specifications

The buyer usually has certain key specifications in mind, including the pulse width, rise time, fall time, current amplitude, and repetition rate. However, it is also important to understand limitations within the driver, such as compliance voltage and maximum internal power dissipation (duty cycle), which we discuss later.

Current source theory

Since laser diodes and high-power LEDs are usually driven by current sources instead of voltage sources, let's take a brief look at current source theory.

An *ideal* current source is able to supply unlimited voltage, which means the voltage across its output is determined solely by the load resistance. So, an ideal current source cannot contain any internal resistance in parallel with its output and thus has an infinite output impedance.

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The model of a *real* current source is a resistance in parallel with an ideal current source; the current through the resistor determines the voltage.

From this description we see that a pulsed-current driver should not be used to drive an open circuit or high impedance load, such as a small capacitance or large resistance; obviously, no amount of voltage can drive a current through an open circuit. Under those conditions, the driver will attempt to output the maximum available voltage, called the *compliance voltage*. Depending on the model, protection circuits may be activated and/or damage can occur. For this reason it is important to avoid any kind of open circuit resulting from a bad connection, laser diode failure, and so on.

On the other hand, a pulsed-current driver has no problem driving a short circuit because the current is regulated to a specific value.

Compliance voltage

The term "compliance voltage" came from the power supply industry, where it is defined as the range of output voltage (in a constant-current power supply) over which the load regulation is within certain limits.

A current source provides a constant current as long as the load has sufficiently low impedance. But as the load resistance is increased, the voltage required to drive that current increases until a point is reached at which there is not sufficient voltage available to maintain the required current. That's why it is important to know the load resistance (if the load is a resistor) and the forward voltage drop (if the load is a laser diode or LED). The driver cannot provide the required current if the compliance voltage is insufficient.

For example, consider a 60 A current driver that has a compliance voltage of 20 V and typically drives a single-junction laser diode. You cannot test the driver at 60 A using a 1 Ω resistor for the load because the compliance voltage needs to be:

$$\begin{aligned} V &= IR \\ &= (60)(1) \\ &= 60 \text{ volts} \end{aligned} \tag{2}$$

In this case, the resistance must be no more than 20 V/60 A = 0.333 Ω. Note that to test a current pulser, you can short the output and watch the current with a suitable monitoring circuit. The pulser is not damaged by a short.

Many applications involve single-junction laser diodes and LEDs with a forward voltage drop of just a few volts. If you are driving a laser diode *stack* (a group of series-connected laser diodes), be sure to specify a driver with a sufficiently high compliance voltage.

Note that some current pulser models have an adjustable compliance voltage *limit* or an adjustable overvoltage detector. The latter is a safety feature that protects the load (such as an expensive laser diode) by shutting off the output if the voltage across the output reaches the trip point). These adjustments are *not* output voltage adjustments.

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Basic topography #1: the voltage-controlled current driver (PCO-7110, PCO-7120, PCO-7810)

In this type of small driver, energy is stored in a bank of capacitors charged to a high voltage by an external power supply. A logic-level pulse on the trigger input turns on a fast MOSFET switch, which transfers energy from the capacitor bank to the laser diode through a fixed resistance. In DC terms, the output current equals the amplitude of the high voltage supply, less the forward voltage drop of the laser diode and the drop across the MOSFET, divided by the fixed resistance on the board.

Such a design seems simple on the surface, but in reality the components must be "tuned" for proper pulse performance. The values of the capacitors and resistors, the characteristics of the MOSFET, and the parasitic inductances in the PC board's traces, the component leads, etc., all combine to create a pulse of a certain shape.

The use of a voltage source and a resistor to simulate a current source works as long as the load resistance is much smaller than the pulser's internal resistance. The compliance voltage of the small modules is about 20 V, so the load is typically a single-junction laser diode rather than a stack.

The advantages of this type of pulser include small size, simplicity, and low cost since no feedback loop is used. It produces fast, short-duration, high-current pulses.

There are several limitations imposed by this type of design.

One limitation is it cannot produce a wide pulse or a constant-level (CW) output because the capacitors give up energy to the load over time. The result is a droop in output current. For example, the maximum specified pulse width for the PCO-7120 (a 50 A pulser) is 1 µs at 5% droop. The current is only 5 A with a 10 µs pulse. These pulsers are typically operated at very low duty cycles.

A second limitation is a high minimum output current. At low currents, the HV is reduced to the point where there may be insufficient voltage to overcome the diode's forward voltage drop. While you may be inclined to add series resistance to reduce the current, the result is usually a distorted pulse and ringing due to the additional inductance.

A third limitation is a low duty cycle. Small pulsers have little room for dissipating heat into the environment because they depend on a small heat sink or heat spreader to transfer heat to the air from the MOSFET package (and slightly through the PC board).

One of the things a user wants to know is how to size the high voltage power supply. For fixed, narrow-width pulsed-current drivers (PCO-7110, PCO-7810), the power is in the pulse edges. The current required from the high voltage supply is:

$$I = CVF, \tag{3}$$

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where I is the current in amperes, C is the sum of various capacitances in the driver and is provided in the manual, and F is the pulse repetition rate. To get the average power in watts, multiply the current by the power supply output voltage.

For drivers with adjustable pulse widths (PCO-7120), the average power required from the supply is:

$$P = V \bullet I \bullet duty\ cycle, \tag{4}$$

where P is the power in watts, V is the voltage in volts, I is the current in amperes, and $duty\ cycle$ is the ratio of the pulse width to the period.

Basic topography #2: the inductive-storage current driver (PCO-6131, PCO-6141, PCX-7420, PCX-9000)

These drivers store energy in large inductors. The output current is continuously measured and fed back to a control loop that maintains a precise current regardless of load characteristics. The output remains shunted until the pulse occurs, but because it is a current source, no harm results from the shorted output. The MOSFETs and other components get warm from switching losses and other losses, but the dissipation is relatively low when MOSFETs are used in switch mode.

Because the output is turned on and off with a shunt (sometimes called a *crowbar*), this system offers very fast rise times of generally less than 100 ns and a wide range of pulse widths. Also, the short across the laser diode before and after the pulse provides a measure of protection from stray voltages such as static electricity.

A characteristic of the inductive-storage driver is the pulse fall time is dependent on the inductance of the load and output cable. To explain this last point, note that when a large current flows, considerable energy is stored in the circuit’s inductance. When the pulse ends, current continues to flow in the load as the magnetic field in the load and its cable collapses, which results in elongation of the pulse.

This type of driver does not include zero current in the range of outputs. Instead, ranges are given such as 2 A to 22 A for the PCX-7420 and 150 A to 600 A for the PCX-9600. That’s because the circuitry needed to produce high-current pulses includes paralleled power MOSFETs (with their nonlinear gate drive characteristics), large inductor circulating currents, special high-current sensors, feedback loops tuned for large currents, and so on. At very low currents the output may become noisy and more difficult to control.

Care must be taken to ensure the load is never open during operation.

Basic topography #3: the capacitive-storage current driver (PCX-7401, PCX-7500, PCM-7510, PIM-Mini)

These drivers store energy in a bank of capacitors. As in the inductive-storage drivers, the output current is continuously measured and used as feedback to a control loop.

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A characteristic of the capacitive-storage driver is a slower rise time than the inductive type. The slower rise time actually is a benefit in some applications because it allows for a longer output cable and the ability to use a twisted pair cable instead of stripline. Also, an open load does not damage the driver.

The capacitive-storage driver generally outputs less ripple current than inductive-storage types, with little to no overshoot.

Bias current and pulse current

To minimize the laser diode's response time to a pulse, some laser drivers offer a bias current feature. It involves an additional current supply with its own control loop plus a circuit that sums the bias and pulse currents.

The idea is to deliver current in two steps. The first step is the bias pulse, which starts shortly before the intended trigger time. Bias current is set just below the lasing point. When the main pulse starts, its current adds to the bias current and fires the laser more quickly than a nonbiased system does. However, it is important to remember both currents when setting up the driver to prevent damage to the laser.

Output polarity

It's always important to observe the polarity of a semiconductor load such as an LED or laser diode to prevent damage to both the load and the pulser.

Impedance matching, maximum power transfer

A current source has a high output impedance, so maximum power transfer is difficult to attain with a low-impedance load. Frankly, things like pulser output impedance, load impedance, cable impedance, matching networks, and maximum power transfer don't matter very much in the pulsed-current driver world and there's little need for extra resistors and a matching network. In fact, those components and their leads will add even more unwanted inductance to the output circuit.

Rise and fall times

A major requirement for laser diode drivers involves speed; fast rise times and short pulse widths are desirable when driving laser diodes for ranging and digital communications. Furthermore, although customers would like to see a perfectly rectangular pulse, it is not what one typically gets.

Pulses have a more-or-less trapezoidal shape, and the rise and fall times are typically measured at each edge between two points: one at 10% and the other at 90% of maximum current.

Customers do not generally care as much about fall times, and fall times may or may not be specified depending on the topography of the pulser (some pulsers *source* current but do not *sink* it).

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If the customer wants a narrower pulse, he can reduce the width of his trigger pulse. But he will not be able to reduce the rise and fall times.

Output cable

Because laser diode drivers usually involve large currents and fast rise times, low inductance techniques are needed to get good pulse performance and to protect the instrument and the laser diode from voltage transients.

Each pin or contact in a connector has inductance. Because total inductance is reduced when inductors are placed in parallel, the pulser's output connector is wired with multiple pins or contacts in parallel.

The cable itself consists of two wide, flat, parallel copper conductors and is sometimes referred to as *stripline*. If the conductors are symmetrical and closely spaced, the magnetic field created by the current in one conductor is mostly cancelled by the opposing magnetic field created by the other. The result is a low-inductance cable. Minimizing the inductance reduces *ringing* on the pulse waveform. Ringing is destructive if its negative peak voltage exceeds the reverse bias limit of the laser diode.

Connecting the cable to the laser diode can be a challenge for certain laser packages. Do not use pigtails to adapt the stripline to the laser because even a few inches of round wire adds a few nanohenries of inductance, enough to distort the pulse at high current rate of change. It is best to solder the diode directly to the stripline, separating the stripline conductors as little as possible to avoid creating a loop. (A loop appears as an air-core inductor to the current.)

Another idea is to lay out a simple two-layer PC board that adapts the stripline to the laser diode. One stripline conductor is soldered to each side of the board, turning the board into an extension of the stripline. A radial-leaded package can be mounted perpendicular to the board, while an axial package can straddle the edge of the board. The board can include holes or cutouts to match the laser package, and separate boards can be inexpensively produced to interface with different packages.

Don't extend the factory-supplied stripline. On the other hand, if the stripline is longer than needed, it can be shortened without ill effect. Bending the stripline is acceptable, but care must be taken to not separate the conductors, which increases inductance. Keep it away from other conductors.

Grounding the output

If we view the pulser and its stripline as a system designed for identical currents in the two conductors, it becomes apparent that neither the anode nor the cathode of the laser diode may be connected to ground. That is, the laser must *float* for several reasons:

- The pulser's internal control loops depend on accurate current measurements. If the laser current finds another path to ground, the measurement – and thus the output current – will be inaccurate.

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- The stripline cable's performance depends upon how well the incoming and outgoing currents match. Leakage currents upset the match and reduce the benefits of using stripline.

- For safety reasons, we don't want current flowing from the laser fixture and table through a person or conductive object to ground.

If one side of the laser diode is connected to a conductive package, use nylon hardware to mount the laser package or place insulation between the laser package and the table as needed.

Measuring the output pulse

It is important to have a good picture of the output pulse, and for this job users sometimes grab a handy oscilloscope probe and place it across the load. Unfortunately, looking at the voltage across the laser diode with a high input impedance oscilloscope doesn't provide a good picture of the pulse, especially when dealing with a current pulser and a current-operated load (the voltage will comply as needed to keep the current flowing). In addition, an ordinary oscilloscope probe has a long ground wire that easily picks up noise from the large currents being switched nearby.

Using two probes isn't any better because the math ability on most scopes isn't fast enough to keep up with high speed pulse edges. If you must look at the voltage, a better tool is a high-speed differential probe. (Note that some pulser outputs can be at high voltage, and thus the differential probe must have an appropriate voltage rating.)

The best idea is to monitor the output current using either the pulser's I_{MON} (current monitor) output if provided, or a current monitor accessory board. The current monitor is made up of a group of very low value resistors in series with the output. The resistors convert the current to a scaled, real-time voltage signal to be viewed with an oscilloscope. The specification sheet provides the conversion ratio, such as 1 V per 20 A of output current. To reduce noise, the current monitor output is 50 ohms and is intended to drive a 50 ohm terminated oscilloscope input. However, it is still possible that the current monitor signal is noisier than the pulse as measured with optical means. The signal developed across the current monitoring resistor is a low voltage and is viewed using a sensitive range on the oscilloscope, which can pick up noise from nearby high pulse currents.

When monitoring the current, be sure to float the oscilloscope, and be sure to connect the scope ONLY to the current monitor connector. The current monitor output floats, and connecting the oscilloscope to other equipment may result in a damaging current flowing in the test equipment.

Do not use standard scope probes to connect with the header connector on the small, board-level drivers. If the proper cable is not handy, you can make one up with three feet of RG316/U cable with a BNC plug on one end for the oscilloscope. The other end can be tack-soldered to the pins, keeping the exposed inner conductor as short as possible.

Trigger input

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The trigger input is 50 ohms to greatly reduce false triggering from noise. Although many function generators can output 5 volt logic-level pulses, not all can maintain TTL levels when driving a 50 ohm load. One that can is the DEI Scientific PDG-2500.

Problem solving: Ringing

Ringing (or overshoot) is a damped sine wave and is a major issue caused by excessive inductance. If you do not minimize it, it will override the other pulse fidelity issues.

Note that:

$$V = L \frac{di}{dt}, \tag{5}$$

where V is the voltage in volts, L is the inductance in henrys, and di/dt is the change in current over a specific period in amperes per second. The voltage across the inductor increases with the inductance and with the current rate of change (di). During the leading and trailing edges of a pulse, di can be very large (tens or hundreds of amperes) and dt can be very small (nanoseconds or microseconds). Just one nanohenry of inductance, when multiplied by a current rate of change of, say, 10 A in 10 ns, results in a one volt reverse voltage.

Inductance is everywhere, from PC board traces and component leads to the load itself and its cabling. Energy stored in the inductors' magnetic fields during the pulse is released when the pulse ends, resulting in a voltage that creates a new current that creates a new magnetic field, and so on.

Inductive-storage pulsers end a pulse by placing a shunt across the output. If there is a lot of inductance in the output circuit, a circulating current may occur that extends the falling edge.

If you are building a resistive test load, use multiple large SMT resistors in parallel to reduce the inductance. One technique is to solder the resistors across a gap in the PC board plane and then solder copper foil over the edges of the board to bridge the top and bottom layers.

Problem solving: Noise on the output

The smoothness of the pulse is affected by the design of the pulser, particularly in those designed for a wide output current range.

For example, inductor storage pulsers may show ripple on the output that is actually part of the operation. As energy is removed from the inductors to feed the load, new energy from the power supply recharges the inductors. The charge/discharge cycles don't occur at regular intervals but rather upon demand, so what is actually ripple looks like noise. The ripple is more obvious at lower output currents, and for this reason a minimum current specification appears on the datasheet.

Noise can be lowpass filtered to some extent by adding a circuit called a *snubber*. A series-connected resistor and capacitor is connected across the load. High frequencies are reduced, but some of the energy is returned to the load just after the rising edge of the pulse. This results

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in the pulse waveform picking up a “ripple” appearance. Because the waveform gets distorted in this way, the snubber’s R and C values are usually chosen to have a mild effect.

Summary

Laser diodes and LEDs are current-operated devices. By understanding the electrical properties of current drivers, the correct model can be selected for many different applications.

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