Compact Laser Diode Drivers for Military Rangefinder Applications[1]

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Compact and high current laser diode drivers for pumping solid-state lasers have been developed and tested. Designed to operate from a single DL123 battery or equivalent, the OptiSwitch PLDD-150-1-1 delivers 150 A of peak current for 300 µs to a laser diode bar at a 1 Hz repetition rate. Measuring only 2.1 x 0.75 x 0.78 inches and weighing 15.2 g, the unit is suited for man-portable target designation, rangefinding, illumination, and remote sensing applications. This paper will discuss the design philosophy behind this class of drivers which offer peak currents up to 200 A plus lifetime testing of eight drivers all operating at elevated input voltage and temperature at 4.5 Hz for 10M shots without a single failure or degradation in performance. Lastly, temperature testing down to -40 degC will be discussed.

Keywords: pulsed laser diode drivers, military rangefinders,

1. INTRODUCTION

Compact laser rangefinders, target designators, and markers are of increasing importance to the military. The optical pulse from a rangefinder can be generated directly by a diode laser or by a diode pumped solid-state laser. Target designators and markers are all based on a diode pumped solid-state laser that is either actively or passively Q-switched. Due to the timing jitter associated with passively Q-switched laser, passive Q-switching is used only in marker applications.

Most drivers for diode lasers are capacitor based. In these types of drivers the energy is stored in a capacitor and a switch is used to deliver the stored energy to the laser diode which in turn pumps the solid-state material which is typically Nd:YAG. Due to the high energy storage of Nd:YAG (~2 J/cm^3) and the low energy storage of a typical capacitor, the size of the storage capacitor(s) typically dominate the size of most hand-held or airborne pulsed laser systems. In addition many capacitor types have problems with operation at reduced temperatures (<-10 degC) due to the increase of the internal resistance and/or reduction in capacitance.

In this paper we will discuss our design philosophy for an ultra-light weight, 150 amp (120 amps at -40 degC) 1 Hz driver that produces pulses of 300 µs into a nominal 2 volt load (see Figure 1). This driver is ideal for driving a single 808 nm laser diode bar which can be used to pump a solid-state laser for a compact rangefinder. We will discuss extensive lifetime testing and operation at -40 degC.

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Figure 1. Photograph of the PLDD-150-1-1. This driver weighs 15.2 grams and can deliver 150 amps in 300 μs at 1 Hz to a single laser diode from -40 to +70 degC. It can run off a single battery (DL123 or equivalent).

2. CAPACITOR SELECTION

The energy density of a capacitor (W_d) is given by:

$$W_d = \frac{1}{2}\varepsilon_0 \varepsilon_r E^2$$

Where E is the electric field in V/cm, ε_o is the dielectric constant of free space in F/cm and ε_r is the relative dielectric constant. The above equation indicates that the largest gain in energy density can be achieved by using a dielectric material that has the largest operating electric field. In fact, capacitors designed for pulsed power made from high quality dielectric films, can achieve close to 3 J/cm^3, but this is only at voltages of >10 kV. For this application much lower voltages are required; film capacitors with voltages of 5-50 volts have a much lower energy density which makes them unsuitable for this application. Other potential capacitor types for this application are 1) aluminum electrolytic, 2) super capacitors (supercaps, ultracapacitors, electrochemical double-layer, organic capacitors, and EDLC), 3) tantalum (hybrid), and 4) ceramic. Ceramic capacitors have excellent low temperature operation but their low capacitance per chip means an exorbitant amount of components are required to reach the milli-Farad level necessary for these drivers. For example, Panasonic and Taiyo Yuden both make a 10 μF, 35 volt ceramic capacitor, but at 10 μF over 1000 parts are required which would result in a large and heavy driver.

High energy density tantalum capacitors are a possibility and definitely should be considered. However, they are very expensive and the equivalent series resistance (ESR) can be quite high resulting in more dissipation. Furthermore, hermetically sealed versions have excessive equivalent series inductance (ESL) making them unusable for <10 μs risetime pulses.

There are two problems with super capacitors when trying to extract high currents in pulses of 200-300 μs duration. The first issue is with the relatively high ESR in conjunction with the low operating voltage of ~2.7 volts. At 120 amps the ESR cannot be greater than 5 mΩ while still being able to deliver ~2 volts to the laser diode. Typically the ESR of most super capacitors is >20 mΩ. In order to reduce the ESR and achieve 2 volts of compliance multiple capacitors are necessary, which would increase the size and weight of the driver. The second issue is with the ability of these devices to deliver short (200-300 μs) pulses of current. As shown in Figure 2 the actual capacitance for short pulses is much less than the DC capacitance[2].

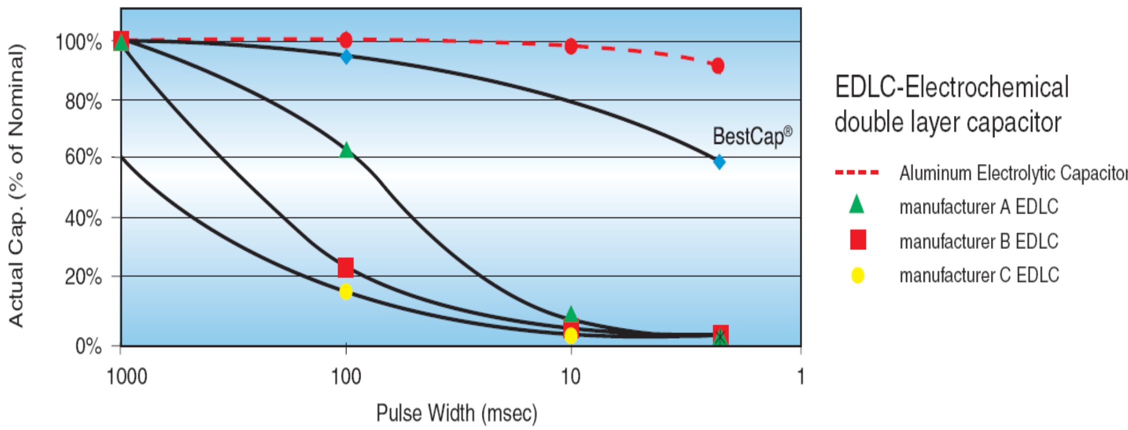

Figure 2. Capacitance versus decreasing pulse width for the aluminum electrolytic, AVX's BestCap and various super capacitors.

Based on the above considerations our drivers use aluminum electrolytic capacitors. Ideally one would want the capacitor voltage to be only slightly higher than the load voltage for highest efficiency. However, the energy density of a typical aluminum electrolytic capacitor (Panasonic FC series, 16 x 25 mm and 18 x 35.5 mm) increases with its rated voltage as shown in Figure 3. This plot shows that the maximum energy density is achieved with a 63 volt rating; however, the plot also shows that the percentage increase in energy density past 35 volts lessens which makes a 25-35 volt capacitor the optimal choice for this application.

Operating at a relatively high capacitor voltage compared to the load voltage reduces the efficiency of the system, but for a 1 Hz rangefinder the efficiency is not as critical as it is for a 20 Hz designator or marker application where the average power is ~400 times greater. For the rangefinder the goal should be to achieve the desired number of shots from the battery with the lightest and most compact driver possible. This is the basis for our designs. Making the driver more efficient to achieve additional shots for a single battery at the expense of increased volume and weight does not result in the most optimal design goals.

[2] AVX BestCap catalog

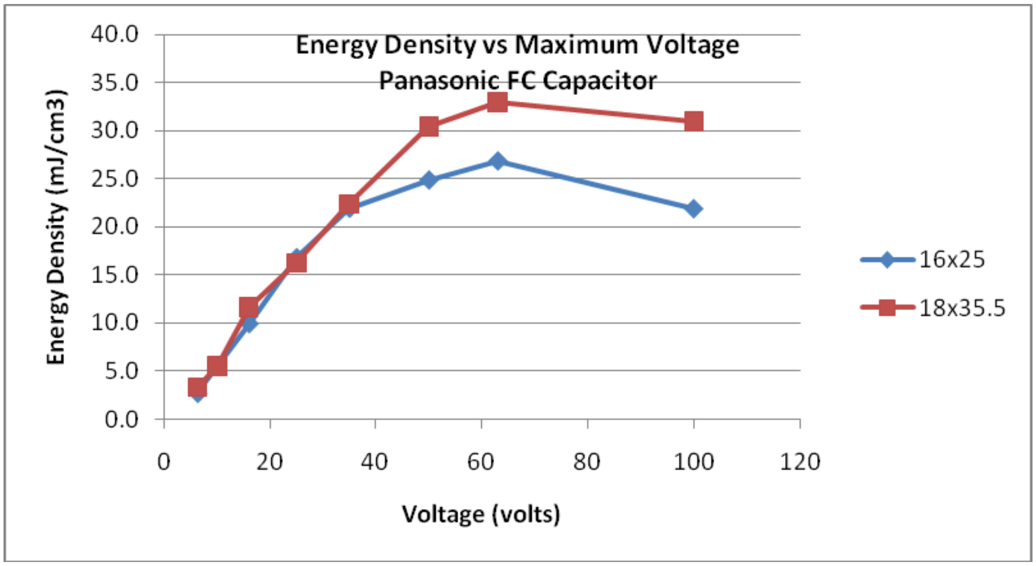

Figure 3. Plot of the energy density (mJ/cm^3) for two sizes of a Panasonic FM capacitor.

3. LIFETIME TESTING

Eight PLDD-150-1-1 drivers were operated for over 10M shots at room temperature with the following parameters:

Reprate	4.5 Hz
Input Voltage	6.0 volts
Load Voltage	2 volts[3]
Peak Current	120 amps
Pulse Width	200 µs

The repetition rate of 4.5 Hz stressed all the components well above their maximum operational values. An eight channel Yokogawa scope was used to gather the data. Figure 4 is a photograph of the eight drivers in operation. A screen capture of the eight oscilloscope traces at the end of the test is shown in Figure 5. The test ended with all the boards still operational. Figure 6 shows the thermal images of the MOSFET, capacitor and capacitor charger. Both are operating well above the expected temperature for 1 Hz operation.

[3] Vishay Schottky Diode P/N: 30BQ060PBF

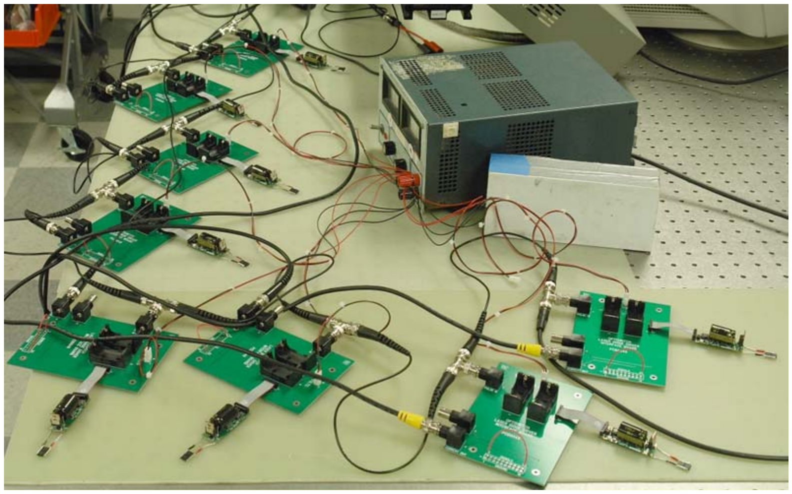

Figure 4. Picture of the lifetime test setup. Eight drivers were operated simultaneously for over 10M shots with no degradation in performance.

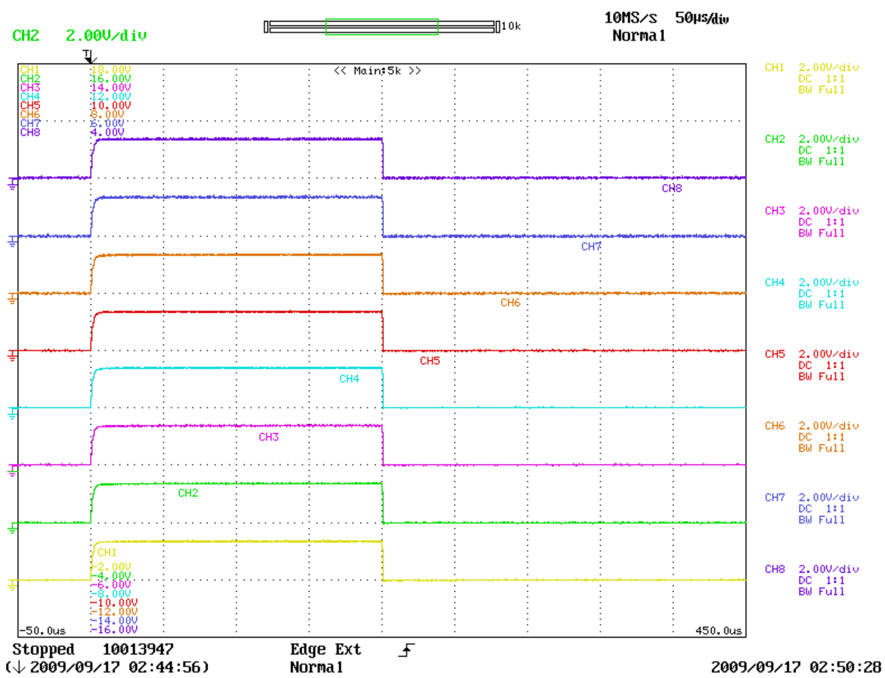

Figure 5. The output of eight PLDD-150-1-1 all ran simultaneously at 4.5 Hz. The shot counter in the lower left shows over 10M shots. At this time the test was stopped.

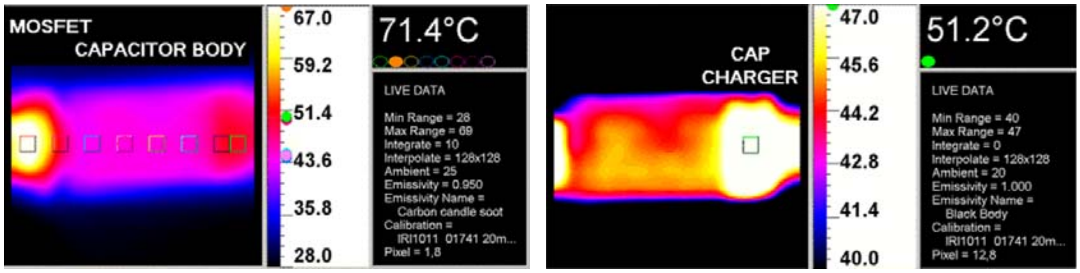

Figure 6. Thermal image of the MOSFET and Capacitor (left). MOSFET is operating at 71.4 degC and the capacitor at ~51.4 degC. Thermal image of capacitor charger circuit which is operating at 51.2 degC (right).

4. TEMPERATURE TESTING

The PLDD-150-1-1 was tested over a temperature range of -40 to +70 degC. The load was three 50 mΩ resistors in parallel, which results in 2 volts at 120 amps simulating a single laser diode bar. The peak current was 120 amps for 300 µs. Figure 7 shows the scope trace of the load current for when the driver was at +70 degC, +25 degC and -40 degC. Before the data was recorded the temperature was allowed to stabilize and then the device “soaked” at the set temperature for five minutes. Notice the well regulated current across the entire temperature range. Only at -40 degC does the load current drop a few percent near the end of the pulse. This is due to the increase in the ESR of the capacitor at the ultra- cold temperature. Identical current waveforms were achieved for all intermediate temperatures.

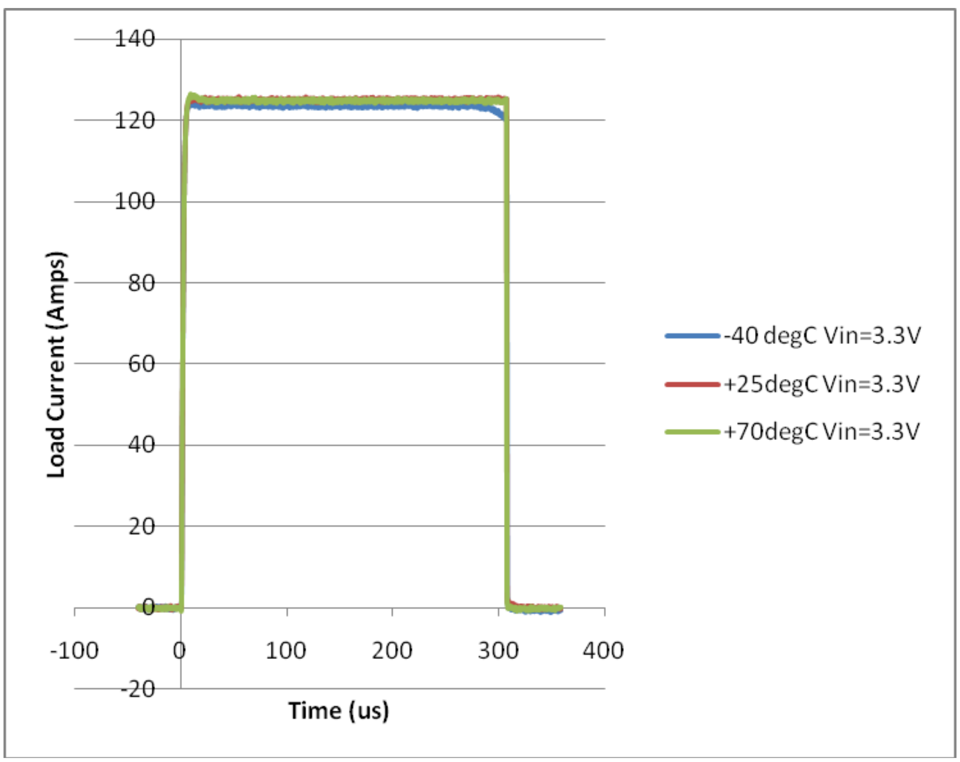

Figure 7. Scope traces of the output current of the PLDD-150-1-1 driving a 2 volt load to over 120 amps (+70 degC, +25 degC and -40 degC)

5. CONCLUSION

The PLDD-150-1-1 is a compact and lightweight driver that uses a single aluminum electrolytic capacitor. The driver can achieve 120 amps of peak current for 300 μs from -40 degC to +70 degC. Higher currents, up to 150 amps, can be delivered down to -20 degC. The authors would like to thank Dr. Lew Goldberg and Mr. John Nettleton at the Army's Night Vision Laboratory for their support.