Quad Flashlamp Driver

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ABSTRACT

Many medical, industrial, and military applications require high pulse repetition rate and high average power lasing devices. To produce higher repetition rates and/or higher average power systems, laser engineers often combine the outputs of multiple resonators using multiple laser drivers accordingly. Previously we used Commercial-Off-The-Shelf (COTS) drivers for this application- each requiring individual pulse timing. The new multiple laser driver significantly reduces cost, size, weight, and complexity as well as improves signal timing. A single AC power circuit, HV DC power circuit, safety interlock circuit, microcontroller, diagnostic circuit and energy storage circuit are shared among multiple laser driver outputs, eliminating redundancy. The method of using a single high power HV charging module allows for reduced size, weight, and component count – improving reliability and dependability. The method of using shared, integrated components improves timing accuracy as external cabling and discrete interface hardware are eliminated.

Keywords: Multiple Laser Driver, Quad Flashlamp Driver, Beam Combining, 4 kW, Urology, Solid-State Laser, Flashlamp Pumped, Pulsed Power

1. INTRODUCTION

Flashlamp power supplies, using Insulated Gate Bipolar Transistor (IGBT) switches to vary pump current pulse width and energy, have been in the market for decades with only incremental improvements in IGBT and gate drive circuits.

High voltage power electronics have advanced in large part due to the demand for electric vehicles (EVs). Technological improvements in Silicon Carbide (SiC) transistors and the high volume needed in the automotive industry have led to improvement in reliability and performance as well as significant cost savings in power semiconductors.

Recently, laser applications in fields such as urology have increased output energy and power requirements – requiring multiple laser driver units and power modules per system. This results in increased space claim and cost, while reducing reliability.

We have contracts requiring higher repetition rate and higher average power laser systems, which necessitates a more advanced laser and flashlamp driver. For applications in Urology, the laser output of four laser resonators is often beam combined.[1] This requires 4 individual channels as well as a 4 kW capacitor charger. The quad laser driver was designed to meet these requirements in a compact integrated package.

The recently developed quad driver is designed for medical and defense applications but is also suited for scientific and industrial applications, including multi-lamp pump chamber and/or MOPA systems.

2. ENABLING TECHNOLOGIES

2.1 HIGH VOLTAGE POWER SUPPLY

We have developed a 4 kW, 1 kV DC power supply using Silicon Carbide transistors and high frequency switching to improve efficiency while reducing cost and size. Silicon Carbide (SiC) transistors have significant advantages over Insulated Gate Bipolar Transistors (IGBT) including higher switching frequencies, lower power losses, increased power density, and higher efficiency.[2]

The material properties of silicon carbide (SiC) enable the use of fast-switching transistor devices in high voltage power supplies. SiC has a breakdown field about ten times higher than Si so the active zone of the semiconductor can be made much thinner. The thinner active zone results in higher switching speeds, lower magnetic size, and higher efficiency. SiC delivers much higher electron saturation velocity and much lower capacitances, providing substantial benefits in higher speed switching and decreased power loss.[3]

2.2 GATE DRIVER

We have also developed a miniaturized, single-channel gate driver specifically optimized for driving the power transistor module. The gate driver directly attaches to the transistor module reducing space claim and improving performance. The galvanically isolated positive and negative gate drive voltages provide fast, controllable turn-on and turn-off of the power transistor module. The driver includes active shutdown and short circuit clamping with high common-mode transient immunity CMTI > 200 kV/µs. Gate drive currents up to 14 A are provided on the separate source and sink pins.

2.3 DIAGNOSTICS

The driver includes hall-effect current and voltage sensors to monitor and display the actual pump energy delivered to the flashlamp(s) for each pulse. Energy storage capacitor bank voltage, flashlamp(s) voltage and pump energy are monitored by the FPGA for safety, error diagnostics and to ensure reliable flashlamp pumping.

3 METHODOLOGY

3.1 ELECTRICAL SIMPLIFICATION

With the presence of the simplified electrical setup, the driver can use a shared capacitor bank, microprocessor, digital and analog, I/O and safety interlocks. Previous methods used four separate drive circuits to pulse a flashlamp driving a solid-state laser. An example equivalent driver circuit (1 of 4) is shown in Figure 1.

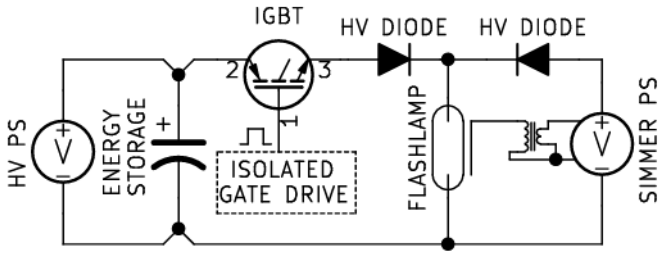

Figure 1 One of four drive circuits used previously

Typically, the HV PS and the energy storage capacitor bank are the largest elements in a flashlamp driver. The new method shown in Figure 2 reduces volume while improving current sharing and energy distribution. Note: EMI and transient protection components are not shown for clarity but have also been optimized for the new method.

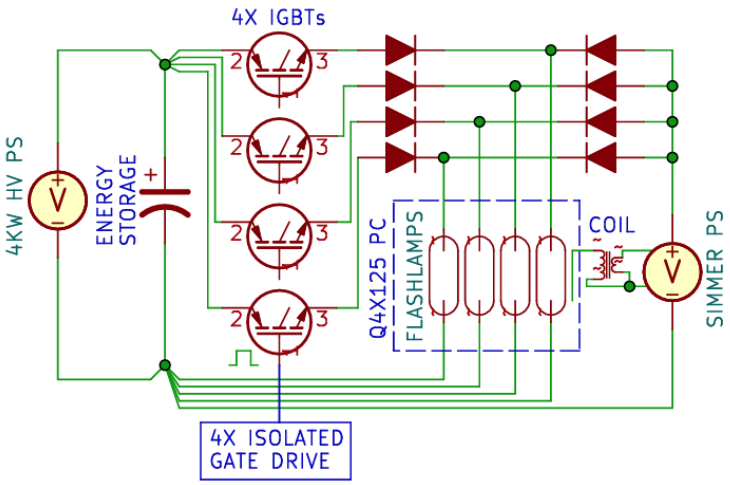

Figure 2 Quad (4X) drive circuits using integrated devices

4 RESULTS

4.1 HIGH VOLTAGE POWER SUPPLY

When compared to Si-based DC/DC converter designs, the SiC-based design resulted in higher efficiency and power density as well as reduced part counts and smaller magnetics.[5]

Table 1 Silicon Carbide advantages versus Silicon

	Silicon (Si) Solution	Silicon Carbide (SiC) Solution	SiC Advantage
Switching Frequency	150 kHz	500 kHz	233% Faster
Transformer/Inductor Volume	48 cm^3	25 cm^3	40% Smaller
Weight	416 g	200 g	52% Lighter

A comparison of the new MegaWatt Lasers 4000 W power supply versus existing competitors is shown below to illustrate the advantages of size, efficiency and cost.

Table 2 Power density comparison between new power supply and existing technologies

	Power (W)	Volume (cm^3)	Efficiency (%)
New Method	4000	4780	91
Existing Method	2000	4886	80

The energy delivered to the flashlamp for each pulse is a function of the flashlamp voltage (V) and current (I) over the pump pulsewidth (t).

$$E=\int_0^t V * I \tag{1}$$

Power of the HV PS is a function of the pump energy delivered to the flashlamp per pulse divided by the recharge time (τ) of the energy storage capacitor bank.

$$P = \frac{E}{\tau} \tag{2}$$

Figure 3 shows a simplified example of an 800 V, 500 µS pump pulse with 312 A current and 106 Joules into an M187 flashlamp that was measured empirically.

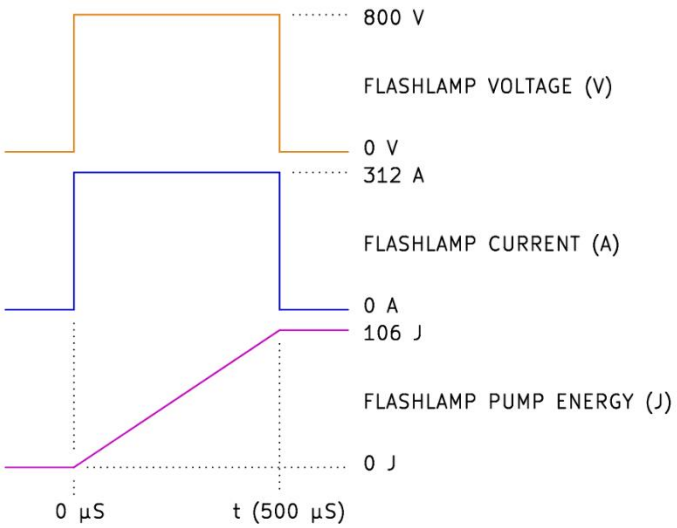

Figure 3 Flashlamp Voltage, Current, and Pump Energy

In this example, the recharge time (τ) of the capacitor bank is ~25 ms. Therefore, the measured power output of the HV PS ~ 4,200 W. Because the HV PS unit is constant power rated, it can achieve > 4,000 W even at voltages below is the maximum operating voltage of 1000 V.

4.2 TIMING WITH MULTIPLE RESONATORS

The Quad Driver can drive up to four resonators either synchronously or asynchronously. We have developed a 200 W, 40 Hz CTH:YAG laser operating at 2.1 µm using this technology.[6] Typical inputs from a motor controller are used to flash four flashlamps while synchronized to a rotating rhomboid prism for beam combining. The firing rate (frequency) in this example is 10 Hz for each resonator. When the four resonators are beam combined, the effective operating rate of the laser is 40 Hz. As represented in Figure 4, the timing for resonator 1 is t_1, resonator 2 is t_2, resonator 3 is t_3, and resonator 4 is t_4. The timing differences in iteration t_{n+1} and t_n is 100 ms in this example due to the firing rate of 10 Hz. The timing difference between resonators is 25 ms due to the number of resonators.

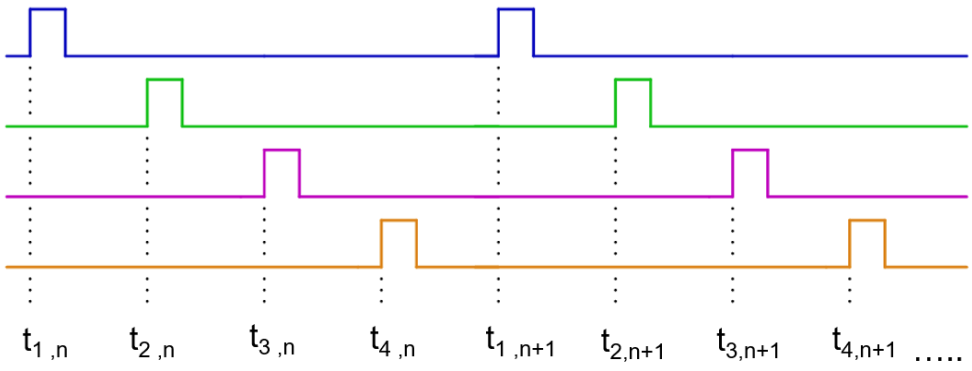

Figure 4 Pulse timing of beam combiner

Using the rhomboid beam combiner, the timing of the individual pulses can be adjusted to precisely align each resonator to the combined beam axis. Likewise, the pump pulsewidth of each pulse can be adjusted to tune the resonators for equivalent output energy.

4.3 ADVANCED FPGA DIGITAL OUTPUT TIMING

Phantom pulses are relatively low energy, high repetition rate pulses of short duration that add power to the laser rod without generating laser output. The phantom pulses are fired into the flashlamp by the laser driver and can be tuned as

needed for the laser material and application. To generate the phantom pulses, a modified pulse routine was utilized. As noted, no additional hardware is required. The 500 µs laser pulse and the phantom pulses were synchronized by their rising edge. Figure 5 shows an example of the timing for the phantom pulses interleaved with the laser pulses.[4]

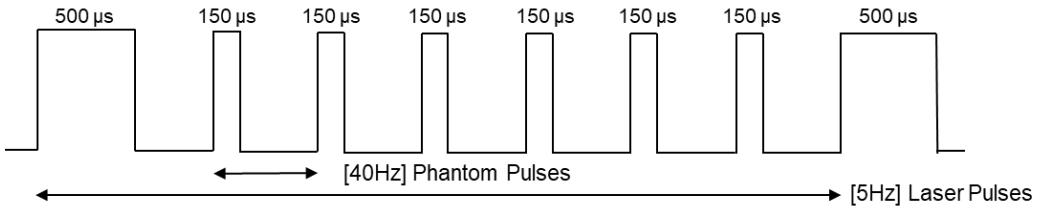

Figure 5 Timeline of 5 Hz, 500 µs laser pulses with 40 Hz, 150 µs phantom pulses (not to scale)

5 CONCLUSIONS

SiC solutions provide a more efficient laser power supply than that of the current state of the art (Si). Gate drivers using combined components reduce the size and complexity of laser driver circuitry and improve system reliability. Shared electrical components allow for a novel method of supporting complicated timing in pulsed laser drivers. Using the new 4 kW power supply and shared components has allowed us to package a four channel flashlamp driver in a space that was previously used for a single flashlamp driver.

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