SUB-NANOSECOND AVALANCHE TRANSISTOR DRIVERS FOR LOW IMPEDANCE PULSED POWER APPLICATIONS.[1]

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Abstract

Ultra compact, short pulse, high voltage, high current pulsers are needed for a variety of non-linear electrical and optical applications. With a fast risetime and short pulse width, these drivers are capable of producing sub-nanosecond electrical and thus optical pulses by gain switching semiconductor laser diodes. Gain-switching of laser diodes requires a sub-nanosecond pulser capable of driving a low output impedance (5 Ω or less). Optical pulses obtained had risetimes as fast as 20ps. The designed pulsers also could be used for triggering photo-conductive semiconductor switches (PCSS), gating high speed optical imaging systems, and providing electrical and optical sources for fast transient sensor applications.
Building on concepts from Lawrence Livermore National Laboratory [1], the development of pulsers based on solid state avalanche transistors was adapted to drive low impedances. As each successive stage is avalanched in the circuit, the amount of over voltage increases, increasing the switching speed and improving the turn on time of the output pulse at the final stage. The output of the pulser is coupled into the load using a Blumlein configuration. The impedance and associated discharge time of this configuration is tailored to the impedance and pulse duration requirements of the load.

I. INTRODUCTION

A multistage avalanche transistor circuit was selected for its ability to produce high voltage pulses with extremely fast risetimes. The purpose of this paper is to give a basic outline of the new pulser as well as provide experimental data of switching semiconductor laser diodes. We have designed and evaluated a driver pulser capable of delivering 85 Vdc into a 5Ω load with a 100 ps risetime and a 160 ps full width half max (FWHM) pulsewidth. The optical pulse from triggered laser diodes are from 30 ps to 160 ps FWHM with peaks powers ranging from 1.1 W to 88mW. Turn on time of the laser is 20ps.

In the current pulser design, there are 6 transistor stages. Each stage drops in voltage by 320 Vdc from its preceding transistor stage. An LC network is formed at each stage with the inductance of ~0.6 mH for each transistor stage and the lump capacitance of the solder pad to the ground plane (4 - 8pF). When the transistors in the lowest voltage stage are closed (shorting the 320V), the sudden increase of differential voltage across the successive stage initiates the switching of those transistors (charged to 640V). That stage in turn triggers the next higher voltage stage (960V) with an even faster turn-on time. This successive triggering of multiple transistor stages leads to avalanche-like initiation of all of the stages and produces an extremely fast risetime on the order of 100 ps in the final stage.

The coupling design between the driver and the output load is crucial to the shape of the output pulse. Previous designs [Fulkerson, 1997b] used a discrete SMT capacitor, 2-5 nF, to couple the final stage of the transistor chain to a 50Ω output. The voltage output pulse widths obtained were typically in the nanosecond regime. For our application, we designed our pulser to accommodate a sub-nanosecond voltage pulse into a 5Ω load. The decrease in both the pulse width and driven impedance had proven to be a challenging concept. Rather than utilizing a fairly large SMT capacitor to couple between the pulser and load, the new design uses a Blumlein structure. The low impedance of the driven load combined with the use of a Blumlein coupling design is believed by the authors to be unique to the application of our pulser.

Pulsed laser diodes with extremely fast turn on times require a sub-nanosecond voltage pulse. Customizing the Blumlein coupling section as well as varying the amount of power delivered to the laser diode by the use of different series elements shapes the optical pulse output to match a specific need.

II. THE DIODE LASER APPLICATION

The concept of our design was built on past technologies as well as the published technical knowledge of Lawrence Livermore National Laboratories (LLNL). The voltage pulser designs of LLNL primarily had focused on driving 50Ω impedance loads using kilovolt voltage pulses with pulse widths of 2 to 20ns [Fulkerson,

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1997a]. One example application of the LLNL designed voltage pulser was in driving Pockels Cells [Fulkerson, 1997b].

The main interest for developing a short voltage pulser was for the electrical switching of laser diodes. Gain switched laser diodes are useful because they exhibit a form of electro-optical pulse compression. A short optical laser pulse can serve as the seed laser in a high energy laser amplifying system to be triggered precisely on-command. Semiconductor lasers can provide high energy optical pulses with precise (< 50ps) command triggering.

The impedance of the semiconductor laser when switched and the diode is in conduction is in the range of a few ohms. The FWHM optical output of a gain switched laser diode is in tens of picoseconds. An overly long voltage pulse (>1ns) would be undesirable in driving the semiconductor laser because of the possible re-triggering and the unnecessary dissipation of energy in the diode after the optical pulse had ended.

This new pulser, dubbed SNLZB2 and based on a formulated template given by [Fulkerson, 1994] operated with the same theory of operation as the LLNL designs[2]. With the interested voltage pulse time scales of less than a quarter of a nanosecond FWHM, proper circuit pad layout was crucial for the minimization of stray capacitance and inductance in the pulser. Shown schematically in Figure 1, the designed SNLZB2 consists of six avalanche transistor stages with each stage having three FMMT417 Zetex avalanche transistors all mounted on a 1/32" FR-4 pc-board with a ground plane underneath. From a high voltage power supply (EMCO Q30), each stage is biased with a 1N5111 MicroSemi 320V Zener diode. The 320V drop that the zeners applied across each of the stages places the Zetex transistors on the very edge of their minimum avalanche voltage of 320V. A SMT 10K resistor is used to separate the capacitance of the Zener diode from the LC stage impedance. All of the components used in the pulser design were surface mounted with short connecting path lengths to minimize stray inductances. The low profile compact design of the pulser provided simple construction, component soldering, and signal inter-connection.

III. PULSER OPERATION

In Figure 1, when a trigger pulse is applied to the primary of the 1:1 trigger transformer, the S1 stage of transistors closes and shorts out the 320V S2 stage voltage to ground. This creates an instantaneous voltage differential of 640V across the transistors of stage S2 causing the S2 transistors to be over-volted and self-break (avalanche). When the stage closes, it shorts the S3 voltage to zero, creating a 960V differential across the S3 stage of transistors. The over voltage causes the S3 transistors to avalanche. A larger instantaneous voltage (1280V) is now across stage S4 which continues the avalanche cycle for the S5, and S6 transistor stages. There is no voltage applied to the output until S6 closes. Once S6 avalanches, the unique design of the SNLZB2 utilizes a Blumlein configuration for coupling to the output load of 5Ω.

The Blumlein configuration is used for two reasons. First when the transistor chain avalanches, empirically it was found that S7 (the pad in front of the S6 transistors) has to have a significant value of capacitance. When the pulser discharges, the charge on the S7 pad dissipates into the lower stages. If S7 didn't have a very big storage capacitance, the rapid RLC discharge of S7 into the lower stages would create a ringing pulse within the stages causing the pulser to back charge, self break, and pulse again. The capacitance used on S7 is three to seven times in area of the preceding pad S6. It was also found that a large S7 capacitance aided in maintaining a low time jitter between output pulses.

Having the pad size of S7 3 to 7 times the size of pad S6 gave an RLC discharge time greater than what was desirable for an output pulse. To minimize pulse ringing, the design needed a large S7 capacitance, but the output coupling capacitance had needed to be small to obtain a sub-nanosecond discharge time into the load. In order to meet both criteria of a large S7 pad capacitance and a small coupling to the load capacitance, the output was designed to be a Blumlein structure. As shown partially in the right of Figure 1, the lower capacitance to the ground plane gives the S7 capacitance. Above which is a coupling capacitance to the output load. The overlapping area of the top layer, coupling to the S7 pad, is adjusted for a desired pulse shape. The more overlap of the load line to the S7 pad, the more the capacitance. With the more capacitance, the longer the temporal width of the output pulse.

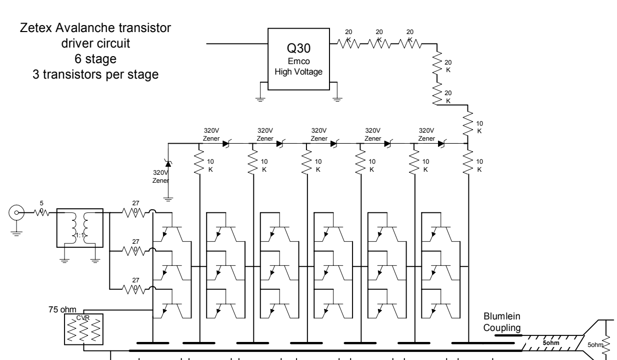

Figure 1. Schematic diagram of the SNLZB2 pulser

IV. DIAGNOSTICS

[2] Fulkerson, The theory of operation of the LLNL designs involved a gradual impedance changed from the triggered end of the pulser to the output coupling capacitor. When the lower stage in triggered, the stage causes the next stage to over-voltage and self-break. The SNLZB2 does essentially that.

The geometry and the physical size of the top layer of the Blumlein both help formulate the characteristics of the shape and time width of the output pulse. To record various voltage waveforms, we used a 50GHz Tektronix's CSA 802 Communications Signal Analyzer with a 20GHz sampling head plug in. A Picoseconds Pulse Labs delay box 1508 supplied the oscilloscope pre-trigger.

The dynamics of specifically how the geometry and overlap capacitance of the Blumlein correlates to the final pulse energy and shape is not well understood. Nominally when the last coupling capacitance to the load is large (as used in the LLNL designs), the pulse output width is on the order of nanoseconds. In the nanosecond time scale, minor variations in the area geometry of the coupling capacitance wouldn't show any significant modifications in the pulse shape. In our application, operating in the sub-nanoseconds, it seemed that any physical variation lead to a change in the output pulse. The parasitic reactance of the pulser to surrounding objects made the characterization of variable attribution to the final output pulse shape fairly difficult. In the circuit, several discrete and parasitic parts to the pulser helped to define the output pulse and for the most part, the output pulse shape was found empirically.

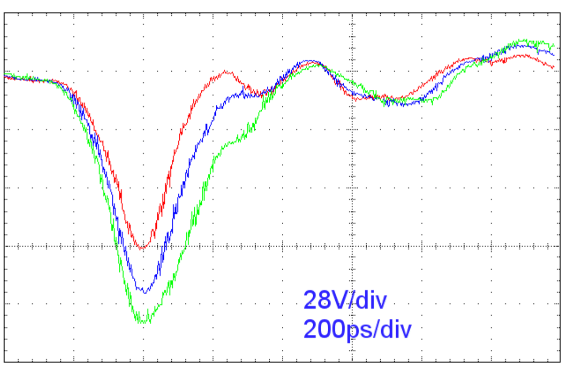

Figure 2. Typical output voltage pulses into a 5Ω load for three different Blumlein geometries.

The primary contributor to the shape of the pulse is the geometry of the Blumlein coupling section. Shown in Figure 2 for three different output pulses with different Blumlein coupling areas, the pulse widths and voltage amplitudes range from 160 ps to 270 ps and 85 V to 115 V respectively with minimal post pulse ringing. Repetition rates of up to 2 kHz were obtained without any device failures or shot to shot pulse distortions. The output time jitter was less than 30 ps.

V. RESULTS

Shown in Figure 3, the SNLZB2 is attached to a 5Ω parallel plate line, the end of which is terminated with nine SMT 50Ω resistors and one 50Ω coax. In parallel with the terminating load resistance is the laser diode in series with an impedance element. This element, either a resistor or a capacitor, limits the amount of power delivered to the diode. By adjusting the impedance of the series element, the voltage across the laser diode can be varied to obtain a desired optical output.

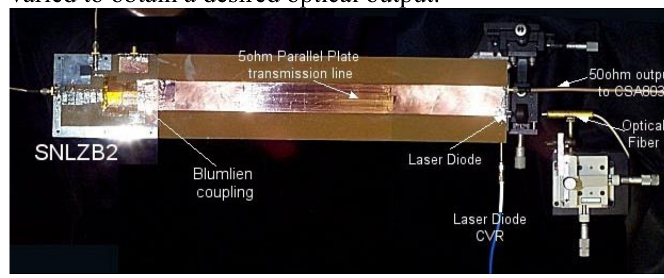

Figure 3. Photograph showing the SNLZB2 test setup

The new pulser was used to test the turn on and gain switching characteristics of two different types of laser diodes. In each case, the voltage across the parallel plate terminating 5Ω SMT resistors was a 160ps FWHM, 85 V voltage pulse. The two different types of semiconductor laser diodes tested were a Sanyo 790nm DL3250-101 and a Rohm 850nm RLD-85PC. The light output of the laser diode was focused into a 50 µm optical fiber and detected using a 25 GHz, photo detector, model 1431-50 made by New Focus. The oscilloscope used was the Tektronix CSA 803A.

The waveforms of the captured light were primarily dependent on the series resistance and capacitance used with the laser diode. The lower the impedance, (either through a lower resistance or higher capacitance), the longer the base pulse width and the higher the laser intensity of the output light pulse.

Shown in Figure 4 A and B, the respective optical outputs of the Sanyo and Rohm laser vary in pulse shape and relative amplitude for different series impedances. As the voltage delivered to the laser rises through decreased series impedance, the optical pulse starts to have a significant amount of energy in the post pulse tail. When the series impedance is high, the laser diodes begin to have more of a bell shaped optical output, which is characteristic of a gain switched laser diode.

The series resistance ranged from 10Ω to 200Ω and capacitance ranged from 5 pF to 47 pF. The turn on time of the two lasers is typically 20 ps in all cases. The pulse widths and amplitudes, dependant on the value of the series element, ranged from 33-105 ps and 25-160 ps for the Sanyo and Rohm diodes. In the Sanyo 790nm case, the temporal optical pulse widths for the capacitive coupling cases are ~20 ps longer than the resistive coupling cases. The same isn't empirically true for the Rohm 850 nm case. Shown in Figure 5 are the vertically scaled 150ohm Sanyo and the 200ohm Rohm optical pulses representing the smallest pulsewidths obtained.

The energy in the optical pulse was measured using a United Detector Technology CCD photocell, serial no. 29821, with a matching optometer S380. Shown in Table 1, the measured energy per pulse ranges from 140 pJ to 3 pJ. Through integration of the output pulse area and correlating that to the pulse energy, the maximum power in Watts per pulse ranges from 1.10 W to 88 mW.

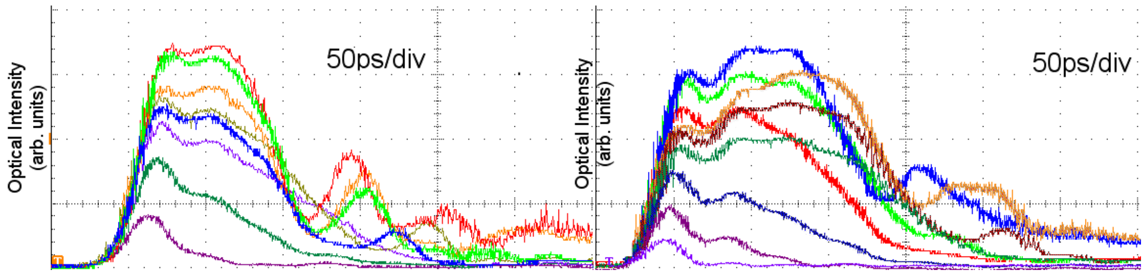

Figure 4 A and B. Light Output Pulses for respective 790nm Sanyo and 850nm Rohm Laser Diode with Different Series Impedances

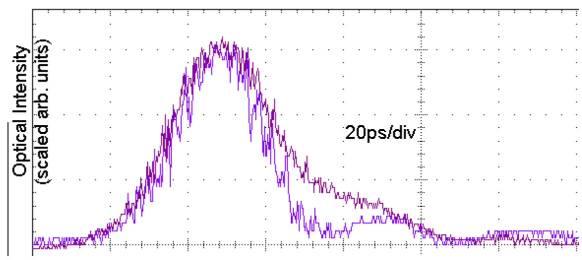

Figure 5. Scaled Optical Pulses for the two Shortest Optical Pulses of the Sanyo and the Rohm Laser Diodes

Element used	Sanyo 790nm Laser Diode			Rohm 850nm Laser Diode	
	Energy per Pulse pJ	Peak Output Power mW		Energy per Pulse pJ	Peak Output Power mW
10Ω	125	552		139	1100
33Ω	56	351		76	440
47Ω	45	314		56	350
100Ω	14	195		20	216
150Ω	4	88		9	164
200Ω	-	-		3	94
5pF	42	423		48	398
10pF	72	646		66	472
47pF	107	550		90	533

Table 1. Energy per Pulse and Peak Power Output for both types of laser diodes tested

VI. SUMMARY

Sub-nanosecond avalanche drivers can be designed for low impedance applications. A Blumlein structure that couples the SNLZB2 to the 5Ω output parallel plate line, matches the impedances and eliminates pulse reflections and ringing. The pulser operates reliably with repetition rates of over 2KHz. By changing the Blumlein geometry, the voltage pulse amplitude and pulse width could be varied over a wide operating range. Voltage waveforms from 85 to 115 Vdc and pulse widths of 160 to 270 ps were attained.

The voltage across the laser diode is adjusted either through resistive or capacitive coupling to give optical intensities and pulse widths that can be catered to suit a desired application. Tests with two different types of laser diodes, produced optical pulses with ~20 ps risetimes, 33-160 ps widths, and up to 1.1 Watts of peak power.

VII. REFERENCES

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