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LOW JITTER AND DRIFT HIGH VOLTAGE IGBT GATE DRIVER

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Abstract

The Cymer Master Oscillator Power Amplifier (MOPA)-based light source requires tight timing control over all operating repetition rates. The newly developed IGBT gate driver allows tight control of the IGBT's turn-on/off timing jitter and drift. Its performance is significantly improved compared to the previous IGBT gate driver. Switching rate improvement of the new driver reduces the time spent in the IGBT's active switching region and therefore helps reduce losses. These improvements allow for better control of IGBT triggering and laser performance. This paper will provide the IGBT gate driver general development approaches, performance and high voltage IGBT switching test results. The new IGBT gate driver meets the requirements for Cymer's MOPA-based laser systems.

I. INTRODUCTION

The Cymer MOPA excimer laser requires two discharge chambers. The Master Oscillator (MO) provides the extremely low bandwidth laser light pulse, while the Power Amplifier (PA) amplifies the MO light to produce the required laser power level at maximum rep-rates of 4 ~ 6kHz [1].

The dual chamber design drives the need for a laser power system with two separate pulse power systems [2]. The design goals for the system are to hold the timing of the two pulses to within ±5 ns of the target timing. It is also necessary that PA pulse be delayed from MO pulse about 25 ~ 50 ns.

An analysis was done of the timing drift and jitter for each of the main components in the laser power system. There are many sources of timing variation. One of the main contributors was the jitter and drift of the SSPPM high voltage IGBT gate drivers. This drove us to develop the low jitter and drift IGBT gate driver with the primary goal of turn on jitter less than 1 ns.

II. DEVELOPMENT APPROACHES

Figure 1 is the block diagram of the IGBT gate driver circuit (IGBT trigger) that we developed.

We use a high-speed optocoupler, fast MOSFET driver, and fast switching MOSFETs to ensure minimum jitter, turn on delay, turn on time, turn off delay, turn off time, power loss, turn on/off drift from low to high operating rep-rates. It is a fully isolated IGBT gate driver using a high isolation voltage optocoupler (optoisolator) and DC/DC converter to isolate the DC power supply and trigger in signal from high voltage side of the circuit. The output P-channel and N-channel MOSFETs are connected with common drains for rail-to-rail output to IGBT gate and emitter to ensure reliable operation. When the trigger in signal is at the low level or no trigger in signal, the output is at the negative rail level to make sure the IGBT is turned off and will not be turned on due to electrical noise. The design effort addressed component selection, circuit board layout and noise immunity.

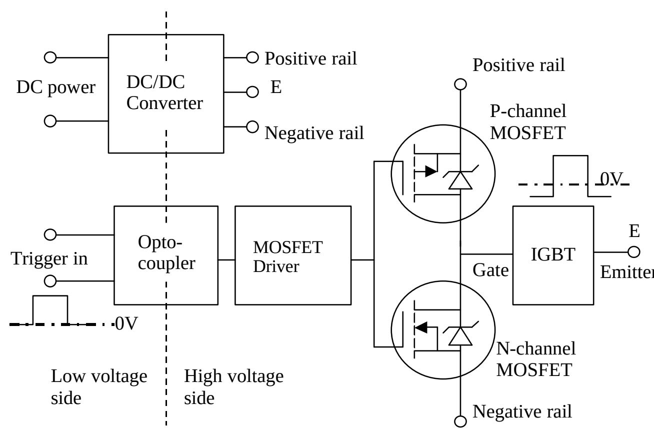

Figure 1. Block diagram of the IGBT gate diver circuit

III. PERFORMANCE OF THE GATE DRIVER

Figure 2 shows the trigger in and output signals of the gate driver with a Tektronix TDS-784D Oscilloscope triggered on channel 1 at 7.5V, driving the Powerex IGBT CM1200HA-50H, running at 6kHz burst mode (6000 pulses/burst, 12000 periods/burst).

Channel 1 is the trigger in signal with 15V rail voltage, 35us pulse width. Channel 2 is the output VGE signal, offset by +6.0V, as the IGBT gate-emitter threshold voltage is about 6.0V. VGE rail voltage is +18.7V/-5.9V.

The gate driver turn on waveform is shown in Figure 3 by expanding the rising part of the waveforms in Figure 2. One can see that the turn on delay is about 79.0ns, and the turn on time is about 27.25ns.

The gate driver turn off waveform is shown in Figure 4 by expanding the falling part of the waveforms in Figure 2. One can see that the turn off delay is about 302ns, and the turn off time is about 62.37ns.

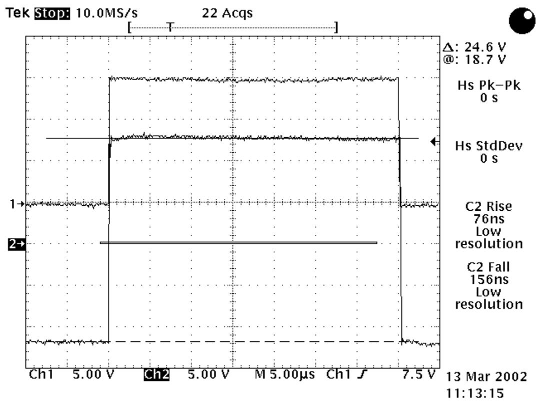

Figure 2. Trigger in and output signal of the IGBT gate driver

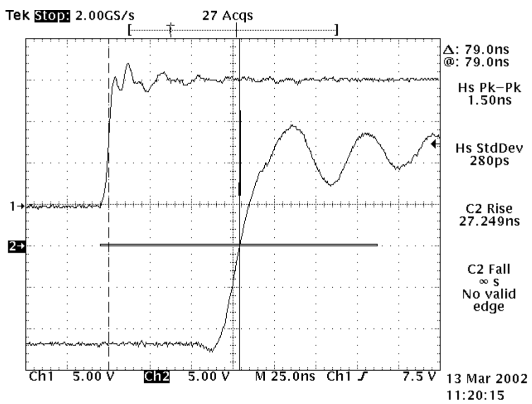

Figure 3. The gate driver turn on waveforms

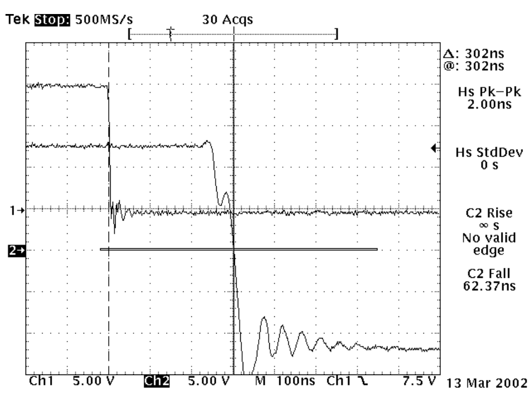

Figure 4. The gate driver turn off waveforms

The gate driver turn on/off jitter was measured using the histogram function of the oscilloscope. Figure 5 shows the turn on jitter measurement, run at 6kHz burst mode for 60 minutes. The turn on jitter is about 580ps (pk-pk). Figure 6 shows the turn off jitter measurement, run for 30 minutes. The turn off jitter is about 920ps (pk-pk) including the first initial pulse divergence. There is no first pulse divergence for the gate driver turning on. The turn on performance is more important to us than turn off for our pulsed power module (PPM) application.

Our previous IGBT gate driver design had significant issues associated with variations in PPM turn on delay as a function of increasing rep-rate [2]. There is no such problem with this improved gate driver.

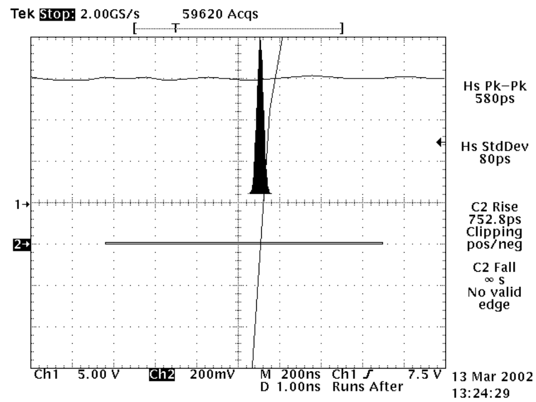

Figure 5. The gate driver turn on jitter measurement

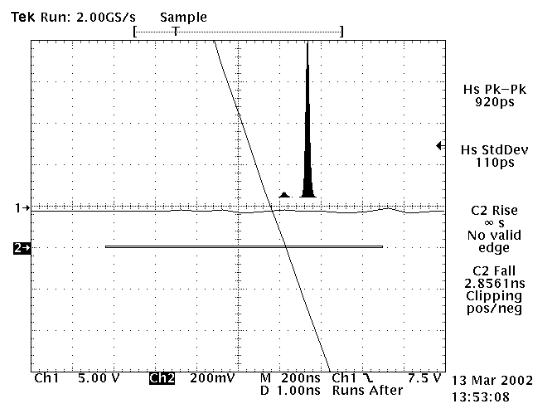

Figure 6. The gate driver turn off jitter measurement

Another important performance of the gate driver we are concerned with is the turn on drift under different operation rep-rates. The turn on drift measurement is shown in Figure 7. We changed operation frequency from 100Hz to 6kHz (continuous mode), ran 30 minutes at each frequency, and measured the peak-peak drift at 1.28ns.

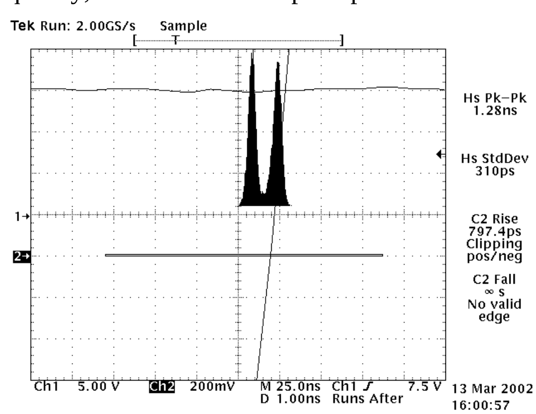

Figure 7. Turn on drift measurement

It should be mentioned that the measured jitter and drift include the jitter contribution from the measuring system itself (the Oscilloscope and the probes), which was measured at approximately 250ps (pk-pk).

The general performance characteristics of the gate driver are listed in Table 1, together with the comparison with our previous gate driver. The IGBT CM1200HA-50H with total gate charge of 5.4μC is harder to driver than CM800HA-34H with total gate charge of 4.4μC. One can see the big improvements on the new IGBT gate driver from the data.

Table 1. The performance characteristics of the gate drivers

Performances data	The gate driver with IGBT CM1200HA-50H	The previous gate driver with IGBT CM800HA-34H
Turn on delay	79.0 ns	458 ns
Turn on time	27.25 ns	383.7 ns
Turn on jitter	0.58 ns (pk-pk)	49.5 ns (pk-pk)
Turn off delay	302 ns	1150 ns
Turn off time	62.37 ns	465.5 ns
Turn off jitter	0.92 ns (pk-pk)	5.48 ns (pk-pk)
Turn on drift	1.28 ns (pk-pk)	Not measured

IV. HIGH VOLTAGE IGBT SWITCHING TESTS WITH TWO GATE DRIVER DESIGNS

We tested the IGBT CM800HA-34H switching performance using the new gate driver and the previous gate driver on the IGBT Test Setup shown in Figure 8. The capacitor C1 is charged by a high voltage DC power supply, and discharged through R2 by switching the IGBT.

The typical waveforms are shown in Figure 9 with the IGBT switching at 1.7kV, in which channel 1 is the trigger in signal of 5us; channel 2 is the VGE signal; channel 3 is the VCE signal measured by a Tektronix P5210 differential probe; channel 4 is the current signal measured by Pearson current monitor at 0.01V/A; and channel Math1 is VCE times current. The area of channel M defined by the two cursors would be the energy loss in the IGBT during that time period. One can find that the IGBT turn on plus conducting period losses are about 0.2168 Joules.

We measured the IGBT turn on loss by defining the IGBT turn on period from trigger in to the pulse current reaching 500A, shown in Figure 10. One can find that the IGBT turn on loss is about 0.0101 Joules.

The IGBT turn on delay and turn on time measurement is shown in Figure 11, in which channel 3 VCE signal is offset by 850V. We can see that the IGBT turn on delay is 300ns and turn on time is 138.4ns.

We also measured the IGBT turn off delay at 865ns, shown in Figure 12. The turn off time measurement may not be very accurate due to the irregular VCE waveform in turn off period.

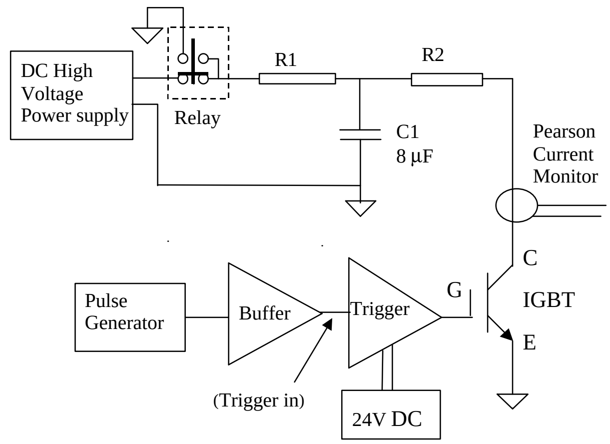

Figure 8. IGBT Test Setup schematic diagram

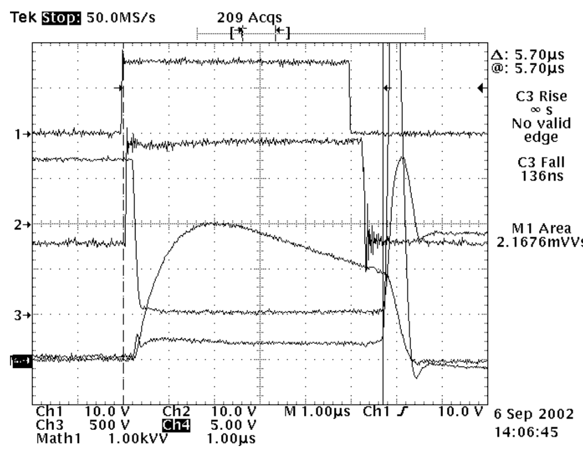

Figure 9. The typical IGBT switching waveforms

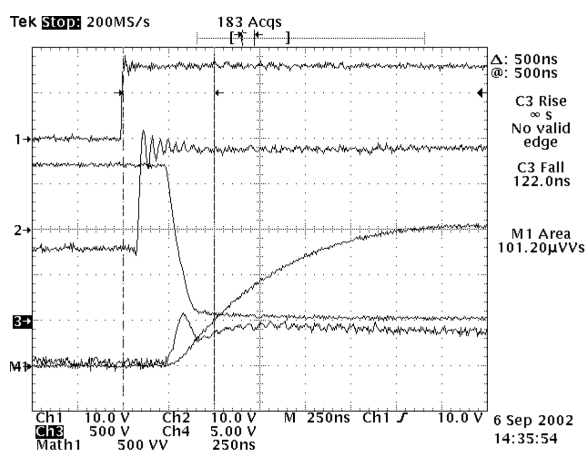

Figure 10. Measurement of IGBT turn on loss

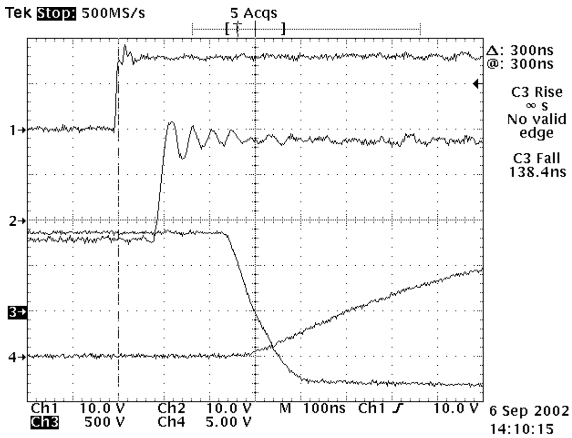

Figure 11. Measurement of IGBT turn on delay and turn on time

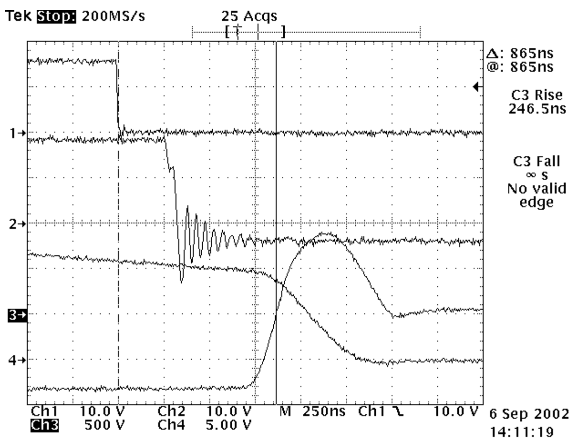

Figure 12. Measurement of IGBT turn off delay and turn off time

The IGBT switching performance characteristics with the new gate driver are listed in Table 2, together with the comparison with our previous gate driver. One can see the significant improvements on the new IGBT gate driver from the data.

Table 2. The IGBT switching performance characteristics

The IGBT switching performance data	CM800HA-34H with the new gate driver	CM800HA-34H with the previous gate driver
IGBT turn on delay	300 ns	785 ns
IGBT turn on time	138.4 ns	238.0 ns
IGBT turn on loss	0.0101 Joules	0.0232 Joules
IGBT turn off delay	865 ns	1870 ns
IGBT turn on plus conducting period losses	0.2168 Joules	0.2631 Joules

We also noticed that the IGBT collector-emitter saturation voltage is about 16.6V (24V minus 7.4V of signal shift with the probe), shown in Figure 13. It is much higher than that in the specification data sheet at about 3.30V. We think that it is mainly due to the short pulse width in our application. There is not sufficient time for the collector-emitter voltage to drop to the low level during our relatively short pulse.

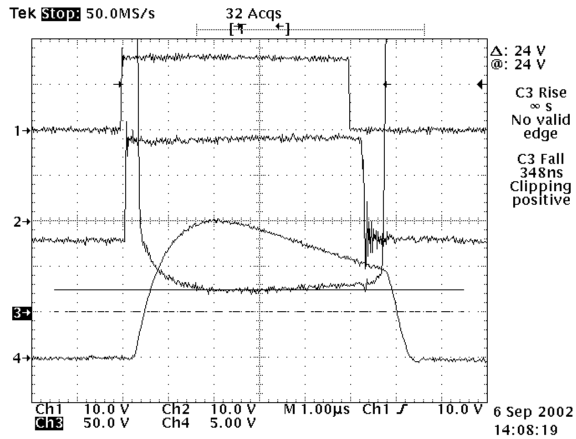

Figure 13. Measurement of IGBT saturation voltage

V. CONCLUSIONS

The newly developed IGBT gate driver is significantly improved in terms of turn on delay, turn on time, turn on jitter, turn off delay, turn off time, and turn off jitter, etc. Also its turn on drift is very small. The IGBT switching performance is improved as well with the new gate driver. It allows us to control the IGBT turn on/off timing very tightly to ensure the proper operation of Cymer's MOPA laser system.

VI. ACKNOWLEDGEMENTS

The authors would like to thank Brett Smith for his expert advice, George Ferguson for accumulating more than 10 billion shots on the test laser with the new gate drivers, and also Terry Houston and John Mounnivong in supporting us to assemble the IGBT gate drivers.

VII. REFERENCES

[1] R. Sandstrom, A. Ershov, and V. Fleurov, "MOPA Laser Architecture for High Power Lithographic Light Sources", presented at the SPIE 27th Conference on Microlithography, Santa Clara, CA, 2002.

[2] R.M. Ness, P.C. Melcher, and R.B. Saethre, "Timing and Synchronization of Solid State Pulsed Power Modules (SSPPM) for Excimer Laser Applications", presented at 2002 International Power Modulator Conference, June 30 to July 3, Hollywood, California.