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RELIABLE, HIGH REPETITION RATE THYRATRON GRID DRIVER USED WITH A MAGNETIC MODULATOR

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RELIABLE, HIGH REPETITION RATE THYRATRON GRID DRIVER USED WITH A MAGNETIC MODULATOR*

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Abstract

The Atomic Vapor Laser Isotope Separation (AVLIS) Program at Lawrence Livermore National Laboratory uses a magnetic modulator switched by a high voltage thyratron to drive a gas discharge laser. The thyratron trigger source must provide an extremely reliable, low jitter, high-rep-rate grid pulse.

This paper describes a thyratron grid driver which delivers a 1.2 kV, 80 ns rise time grid pulse into a 50 ohm load at up to 4.5 kHz repetition rate and has demonstrated approximately 10,000 hours MTBF. Since the thyratron is used with a magnetic compression circuit having a delay time of 1.4 ms this grid driver incorporates a jitter compensation circuit to adjust the trigger timing of the thyratron to provide overall modulator/laser jitter of less than ±2 ns.

The specific grid driver requirements will be discussed followed by a description of the circuit design and theory of operation. Construction comments will be followed by performance data (for a specific thyratron and magnetic compression circuit), including pulse shape, jitter, and lifetime.

Grid Driver Requirements

In its Laser Demonstration Facility (LDF), the AVLIS Program uses a thyratron-switched magnetic compression modulator to drive a gas discharge laser at approximately 4.5 kHz with the requirement for low jitter at the laser output [1]. The thyratron, operating with an anode voltage of 20 kV, requires a trigger pulse of greater than 1 kV and a pulse width of at least 500 ns. A rise time of less than 100 ns is required to keep the change in anode delay time (jitter) of the thyratron low. The grid driver must satisfy these electrical requirements while protecting itself from high voltage transients generated by the thyratron. The grid driver must also withstand fault modes due to thyratron failure such as a shorted or open grid.

The requirement to synchronize the large number of lasers used in the laser system specifies the output of each laser to be temporally stable to within ±2 ns. In this system, the grid driver must accommodate the requirements of the two major sources of jitter: the thyratron circuit and the magnetic compression circuit. The thyratron needs a stable trigger pulse having the proper rise time and amplitude to maintain subnanosecond jitter. The magnetic compression jitter is the result of pulse-to-pulse variations in the total propagation delay resulting from fluctuations in the modulator charge voltage. Propagation delay is defined as the sum of the hold-off times of the compression stages. The grid driver corrects for modulator jitter by adjusting the relative timing of the thyratron trigger pulse on a pulse-to-pulse basis.

If input power is suddenly removed, the self-heated gas discharge laser will cool very rapidly, possibly damaging the laser. To ensure that this is not due to a master trigger failure, the gate driver is required to sense the presence of the master trigger and switch to an internal oscillator when the trigger is lost.

Additional constraints are placed on the grid driver by general laser system requirements. Laser optical stability requirements do not allow heat to be removed by the ambient air. Limited space requires that the physical size of the grid driver be no larger than a 19-inch rack mountable chassis, 3.5 inches high by 14 inches deep. The many diverse requirements of the gate driver make it a challenging unit.

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Circuit Design

The grid driver consists of the three main circuits shown in Fig. 1. The jitter compensation circuit provides the necessary pulse-to-pulse timing adjustment based on measurement of the modulator charge voltage to correct for variations of propagation delay through the modulator. The timing and control section detects a lack of the master trigger and produces its own timing signal and also controls the timing of signals to the high voltage section. In the high voltage section, a capacitor resonantly charged through an FET command charge switch is discharged through a SCR into a step-up transformer. The transformer secondary produces the actual thyratron trigger pulse. We will now discuss each of these circuits in more detail.

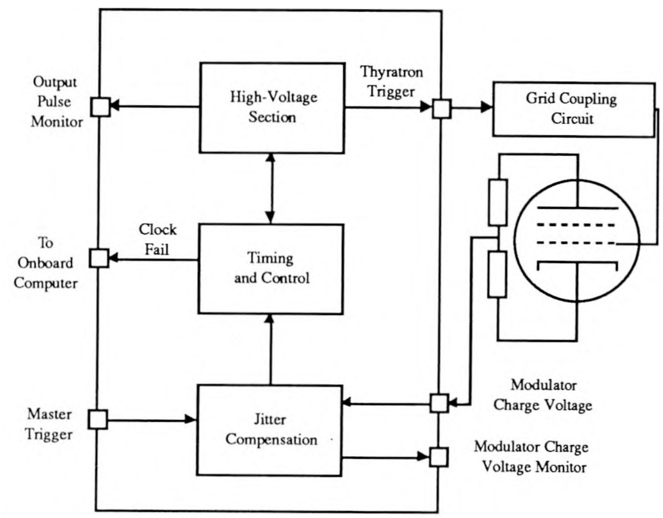

Figure 1. Grid driver block diagram.

Jitter Compensation Circuit

The jitter compensation circuit, shown in Fig. 2, consists of a linear ramp generator, a charge voltage buffer, a high speed comparator, and a pulse shaper. The purpose of the circuit is to produce a constant delay between the master trigger and the laser

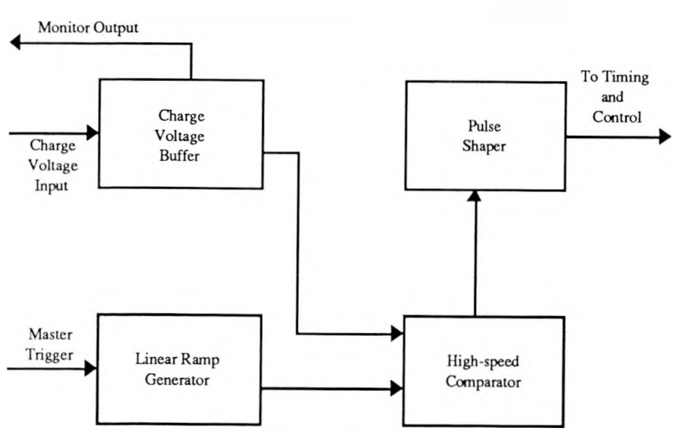

Figure 2. Jitter compensation block diagram.

output pulse. The operational sequence begins with the modulator charge voltage signal being conditioned by the charge voltage buffer. This conditioned signal is the reference input to the high speed comparator. The master trigger then initiates the linear ramp generator which provides the signal input to the comparator. When the signal input exceeds the reference input, the comparator switches and provides a pulse to the pulse shaper which produces a pulse of the proper amplitude and width (+15 V, 100 ns) for the timing and control circuit. After the ramp voltage exceeds five volts, it is turned off and reset to zero prior to the next pulse.

In operation, this circuit increases timing delay when the charge voltage increases and decreases delay when the charge voltage decreases. Because the trigger timing delay is directly proportional to the charge voltage, and the magnetic propagation delay is inversely proportional to the charge voltage, the two effects cancel to produce an almost constant delay between the master trigger and the laser output pulse. The slope of the ramp may be adjusted to obtain minimum jitter at a specific operating voltage.

Timing and Control Circuit

The timing and control circuit, shown in Fig. 3, consists of an oscillator, missing pulse detector, and output timing sections. The internal oscillator provides a 4.4 kHz pulse train to be used if the master trigger is not present (an abnormal situation). In normal operation, the master trigger is greater than 1 kHz.

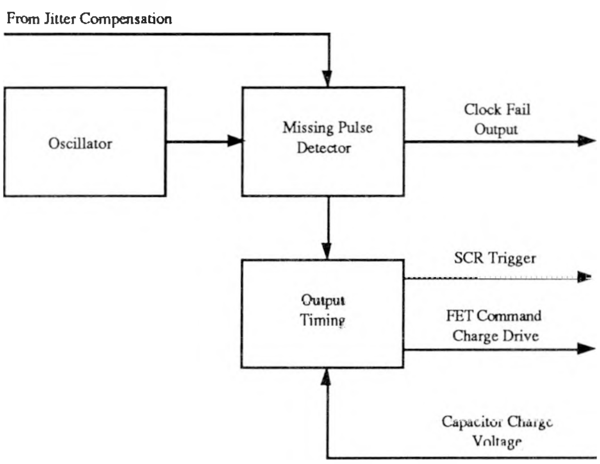

Figure 3. Timing and Control circuit.

The missing pulse detector circuit determines if the master trigger is present (>1 kHz) and gates it through to the output timing circuit if it is. If the master trigger is not present, the oscillator pulse is gated to the output timing circuit.

The output timing circuit produces the SCR trigger and FET command charge drive shown in Fig. 4. The trigger from the missing pulse detector generates a 1 µs wide pulse that is sent to the SCR driver circuit. After a 25 µs delay to allow SCR recovery, the FET command charge pulse begins. If the SCR fails to recover, the charge current goes through the SCR and does not charge the capacitor, and the drive pulse is terminated after 25 µs. When the capacitor charge voltage indicates that the SCR has recovered, the drive pulse lasts for 110 µs to allow for complete capacitor charging.

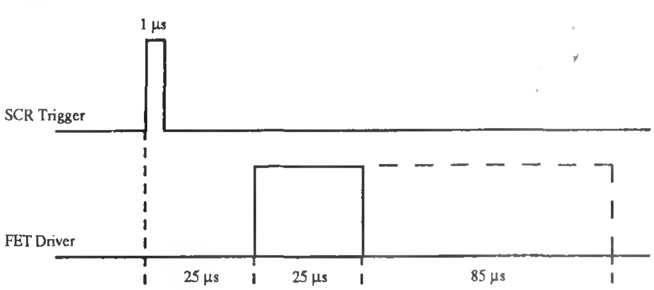

Figure 4. SCR and FET timing signals.

High-Voltage Circuit

The high voltage section consists of the high voltage power supply, command charge, and the output pulse circuit as shown in Fig. 5. The power supply is connected directly to the command charge switch (FET) which charges the main capacitor to approximately 500 V. The main capacitor is then discharged through an SCR into the primary of a four-to-one step-up transformer. The secondary of the transformer has a resistor and varistor snubber to attenuate noise and reflections from the thyratron. Additionally, inverse voltage protection is located in the grid coupling circuit shown in Fig. 1.

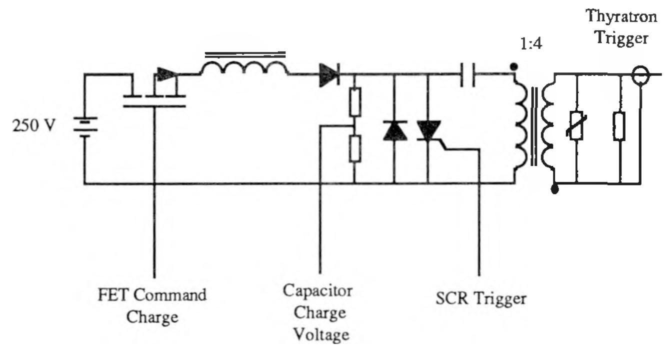

Figure 5. High-voltage section.

Construction

The grid driver is constructed in the 3.5-inch high by 14-inch deep rack mount chassis shown in Fig. 6. The heat generated by the power supplies (side panel mounted) is conducted to the water cooled back panel which is constructed of copper tubing soldered onto a 0.125-inch thick copper plate. As shown in Fig. 6, the printed circuit boards for the jitter compensation circuit and control and timing circuit are mounted on two rails inside the chassis; one printed circuit board above the rails and the other below. All connectors and reference lights are mounted on the boards to simplify installation in the chassis. The SCR and the gate drive protection circuit require active cooling, so they are mounted on the copper heat sink, which is fastened to both the back panel and the trigger generator printed circuit board. Each of the printed circuit boards is readily accessible and can be quickly replaced or removed for repair.

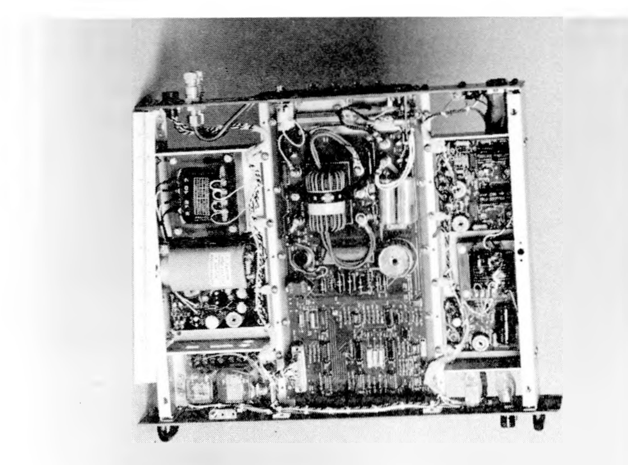

Figure 6. Thyratron grid driver chassis.

Performance

The grid driver output voltage at 4.5 kHz into 50 ohms is shown in Figs. 7 and 8. The output voltage has a rise time of approximately 80 ns (10-90%), a pulse width of 600 ns (basewidth), and a peak amplitude of 1200 V. The jitter compensation circuit maintains the pulse-to-pulse variation of the time interval between the master trigger and the laser output pulse to the required ±2 ns. This number includes jitter due to the switch and jitter due to the pulse compression circuit. Figures 9 and 10 show the laser output pulse with 800 V peak-to-peak charge voltage variation. There is ±10 ns jitter in Fig. 9 which is without the jitter compensation circuit and ±2 ns jitter in Fig. 10 which is with the jitter compensation circuit.

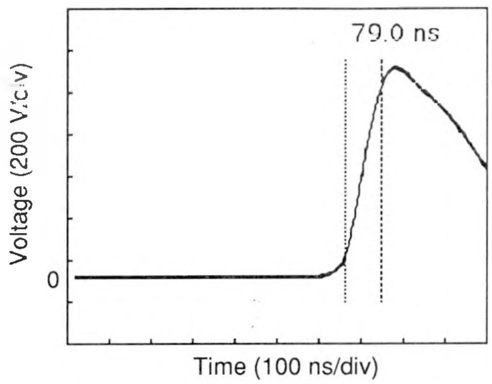

Figure 7. Output voltage risetime into 50 ohms.

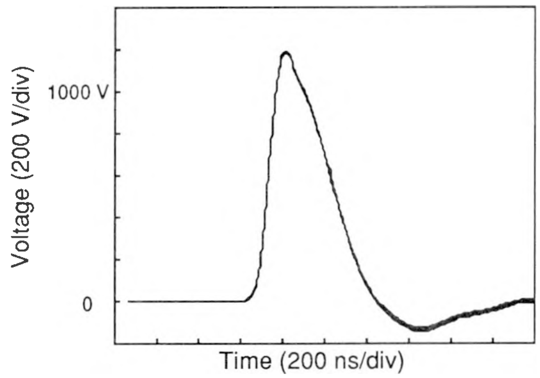

Figure 8. Output voltage amplitude into 50 ohms.

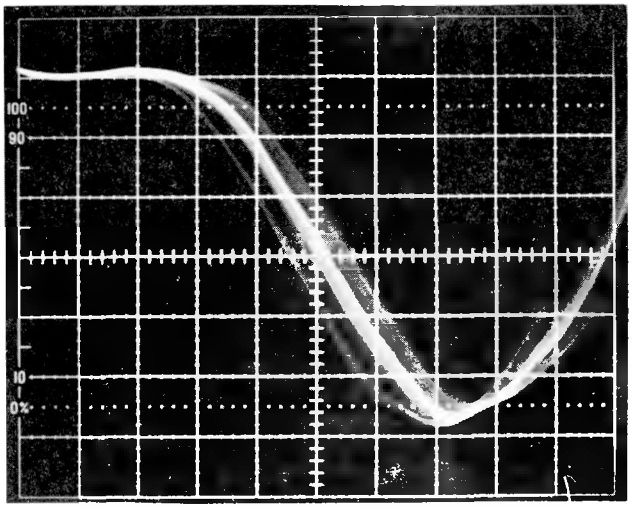

Figure 9. Laser output without jitter compensation circuit and with 800 V peak-to-peak charge voltage variation (20 ns/div).

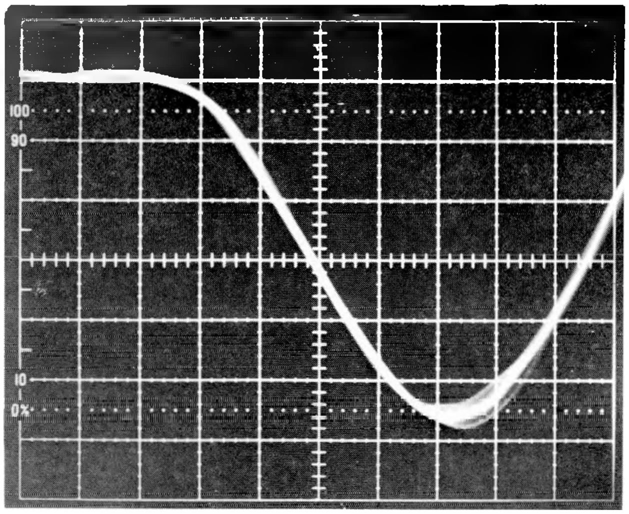

Figure 10. Laser output with jitter compensation circuit and with 800 V peak-to-peak charge voltage variation (20 ns/div).

The reliability of the grid driver operating at 4.4 kHz has been documented for the past six years. The mean time between failure for the 45 units in use is now approximately 10,000 hours.

Conclusion

A grid driver capable of triggering a high voltage thyratron used to switch a magnetic modulator to power a gas discharge laser was designed and operated. The driver successfully demonstrated reliable high repetition rate operation. The jitter compensation circuit reduced modulator/laser jitter from ±10 ns to ±2 ns.

References

[1] E. G. Cook, et al, "High Average Power Magnetic Modulator for Copper Lasers," IEEE 8th Pulsed Power Conference, San Diego, California, June 17-19, 1991.