A LOW JITTER, HYDROGEN THYRATRON POCKELS CELL DRIVER*

J. A. Oicles
Lawrence Livermore National Laboratory
P.O. Box 5508, L-494
Livermore, CA 94550

H. D. Kitchin
The Cardon Instrument Company
Stonebridge House
Earls Colne, Colchester
Essex, CO6 2NL
England

Summary

The requirements to be met by Pockels cell drivers for incorporation into the Novette and Nova Laser systems[1] are presented, and critical aspects of the specification examined. A high performance pulse generator has been developed to meet these requirements using new thyratron technology from the English Electric Valve Co. Ltd. Two closely related versions have been built; a 10KV output unit with 9 nsec risetime into five parallel 50 ohm loads and a faster 5KV output driver with 3.5 nsec risetime into a single 50 ohm load.

The design approach for optimizing performance, using the new tubes in relation to the LLNL specification is described, including the techniques used for control of electromagnetic interference.

Only power and a fiber optic trigger are required for operation of the generators. Output pulse width can be changed in a few minutes using interchangeable internal charge line sets. Circuitry is all solid-state except for the output switch, which is expected to have the excellent life and reliability of modern hydrogen filled thyratrons.

Jitter of less than 0.2 nsec and continuous operation up to 10 Hz rep rate has been achieved. Performance in the laser systems environment, including noise immunity, has been demonstrated and the Novette and Nova laser systems will ultimately employ several of these units.

Introduction

The implementation of large, complex user oriented fusion laser systems at LLNL has placed significant performance demands on the many sub-systems involved. Pockels cell drivers are no exception, and a great deal of effort has gone into perfecting these devices. In the past we have employed gas switch (spark gap) and thyratron technologies for this application.

Although operable, these early units exhibited some performance drawbacks. They were developed in-house and the packaging approach, with much exposed high voltage, necessitated the use of an entire rack bay, with suitable interlocked doors. The spark gap systems required maintenance, often at inconvenient times, and risetime was sometimes difficult to obtain with the thyratrons. In November, 1981, we discovered that English Electric Valve, Ltd. was in final development of a new, fast thyratron, the CX1588. EEV introduced LLNL to the Cardon Instrument Co., which was characterizing the new tube for EEV. Because of Cardon's experience with this device, this company became a candidate supplier of CX1588 based Pockels cell drivers.

Specification

Because of demanding requirements, and in consideration of the physical separation between Cardon and LLNL, a comprehensive LLNL equipment specification, LES 22374, was generated which described a small, rack-mounted unit requiring only mains power and a fiber optic trigger using an LLNL supplied receiver for operation. Because of different Pockels cell driving requirements between the 10 mm duplex cells in the Master Oscillator Room and the five cm single cells in the Laser Bay, two versions of the pulser were specified; the Model A and Model B. The goal was to have the two be as common as possible while fulfilling the individual pulse requirements, which are shown in Table 1.

TABLE 1

SPECIFIED PULSE CHARACTERISTICS

TYPE	PULSE[1] VOLTAGE (KV max)	PULSE[2] WIDTH (nsec)	RISETIME[3] (10-90%) (nsec)	REPETITION RATE (Hz)	OUTPUT Z (EACH LINE) (ohms)	NUMBER OF OUTPUTS	PULSE FLATNESS	JITTER[4] (psec 1σ)	DRIFT[4] (nsec)
MODEL A	5	5-50	< 3	0-10	93	2	10%	< 200	< 1.5
MODEL B	10	10-50	< 10	0-10	50	5	10%	< 200	< 1.5

NOTES:

1. Trimmer adjustable without removing covers.
2. Adjustable in six specified increments.
3. Fall times specified somewhat longer.
4. Jitter is over 10 minutes; drift is over 24 hours.

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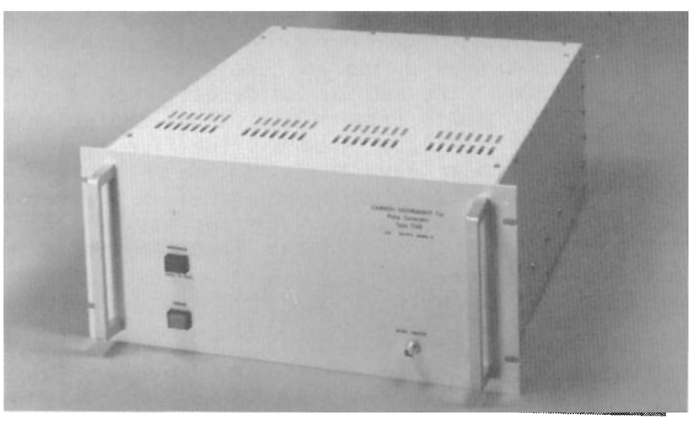
Since these drivers will be used as infrequently adjusted or changed components in a large system, they were specified to have a minimum of external monitors or adjustments. A sync output for monitoring the fiber optic receiver and a signal sampling the output were specified. The power switch on the front panel was the only control required. Cover interlocks would minimize safety considerations and were so required.

Based on past experience with a variety of Pockels cell drivers, trouble-free usability was a recurring theme in the specification. Life (10^8 shots), damage immunity, warm-up time, safety, environment, noise, cooling and weight were addressed to minimize operational impact. Electromagnetic compatibilty aspects were also considered. A separate circuit ground isolated from chassis was called for. Grounding is always an important consideration in large pulse power systems and installation and performance flexibility is enhanced by separation of circuit and chassis grounds. This approach is a design guideline for all fusion laser electronics at Livermore.

Because of programmatic requirements, the Model B was pursued first and this paper concentrates on that unit, shown in Figure 1. As of this writing, however, we are gathering preliminary data on the faster Model A, and performance requirements, which are designed to allow use as a switchout of a mode-locked optical oscillator, appear to be met. With two exceptions, the Nova Laser will rely entirely on Cardon units in both the MOR and Laser Bay for Pockels cell drivers, a total of at least six units. As a backup, we are using a few planar triode drivers built in-house.[2] Also, fast optical pulse carving applicatons will employ a bulk photoconductive semiconductor (Auston) switch based system. This approach will be the subject of future papers.



CARDON 314S PULSE GENERATOR TO LES-22374

FIGURE 1

Choice of Power Switch

The risetimes and pulse amplitudes specified are not presently attainable with commercially available solid state devices, so that the choice of power switching device is restricted to either a thermionic tube or a spark gap. The latter is ruled out by the jitter and life requirements of the specification leaving only the thermionic device.

Here the choice is between a hydrogen thyratron and a high frequency vacuum tube, such as the planar triode. Planar triodes are well established[2] for the generation of kilovolt nanosecond pulses, but suffer from low gain, potentially shorter life when operated at the required high current levels, and restricted current capability.

The requirement to drive five 50 ohm loads in the case of the Model B specification, especially up to 10KV peak output, would necessitate a considerable number of planar triodes and makes the alternative of a single thyratron look very attractive. The gas tube breakdown mechanism provides intrinsically a high gain and high current capability. Moreover, modern hydrogen thyratrons of the ceramic type have an excellent record for ruggedness and reliability. The risetime specification for the B Model of less than 10 nsec has been met by the latest English Electric Valve Co. Ltd. dual grid tube, type CX1588, which has been developed specially for fast switching applications.

In the case of the Model A specification, the need for the equivalent of only a single 50 ohm output load capability makes the planar triode approach worth considering because of the greatly reduced number of tubes needed. However, there still remain life and reliability aspects to consider as well as the specified objective of achieving maximum commonality between the A and B models. The risetime specification is the deciding factor as to whether a hydrogen thyratron solution is feasible and it was fortunate that another EEV Co. thyratron, the CX1599, capable of approaching the required risetime became available at about the same time as the CX1588. Tests on early experimental versions of this tube were reported in 1982.[3]

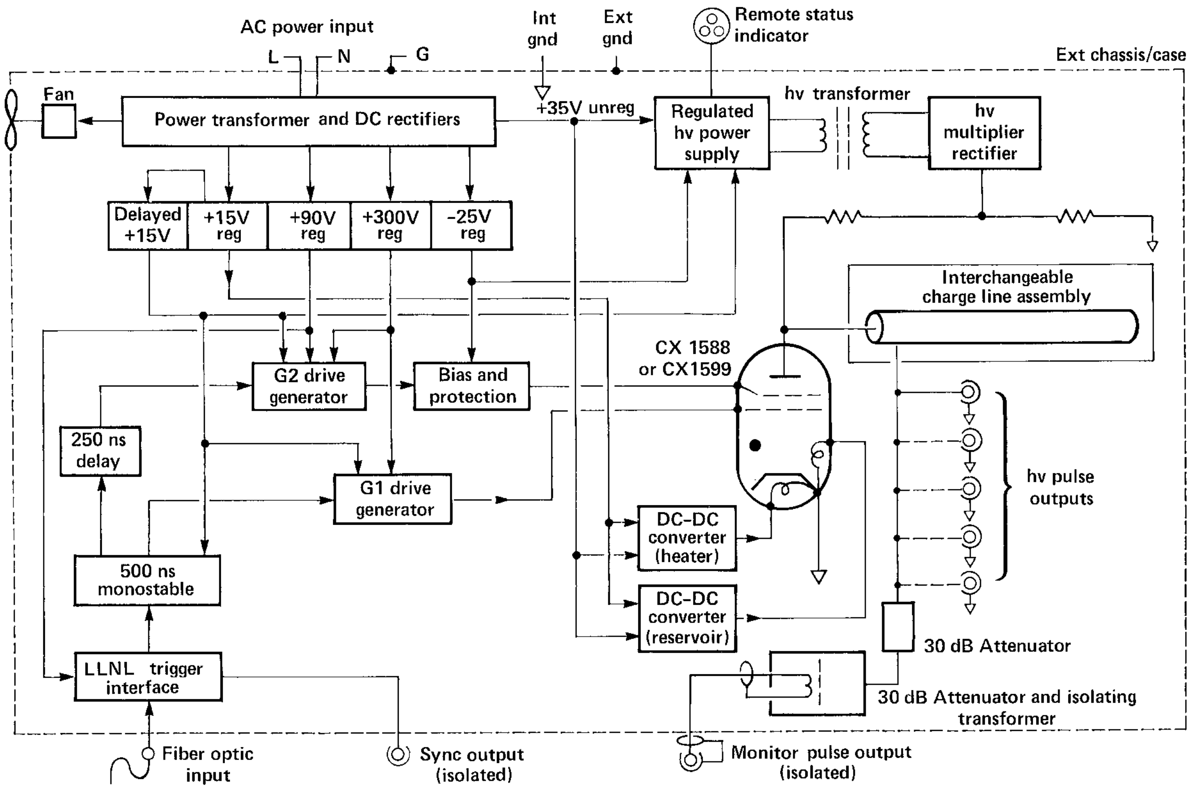
HV Pulse Generation

As the two hydrogen thyratron tubes, CX1588 and CX1599 have the same basic physical construction it was decided to adopt a common design approach to the pulse forming circuit for both A and B models, and the classical charge line configuration was chosen (see Figure 2). To ensure good pulse shape coaxial cable charge lines are used employing proven 50 ohm cable. Some compromise had to be made between the need for sufficient space to accommodate 25 meters of cable in the B Model (for a 50 nsec pulse width) and the desire to minimize circuit stray inductance in the A Model to preserve tube risetime capability. By designing the charge line and tube circuit as a distributed network it has been possible to achieve an acceptable balance between these conflicting factors.

The general physical layout of the charge line and tube circuit is shown in Figure 3 for the B Model. The A Model is identical in concept although slightly different in detail. In each case the charge lines are made as individual assemblies of cables for a particular pulse width and are easily handled during installation and removal. No circuit adjustments are required after changing pulse width, enabling this to be carried out by non-specialist personnel without access to test equipment.

Thyratron Trigger Techniques

To achieve reliability commensurate with the large system application, it was considered essential that all components should be operated within manufacturers' specifications. This has been met by the extensive use of power MOSFET devices in preference

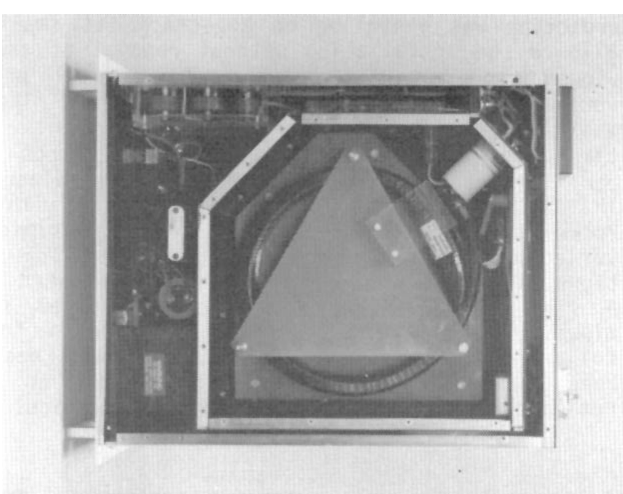


UNIT BLOCK DIAGRAM

FIGURE 2

to bipolar types. Bipolar devices often have to be operated in uncharacterized avalanche modes to achieve the desired performance which can result in unpredictable performance and unreliability.

The increasing availability of power MOSFETS having up to 500 V ratings has enabled series stacks of devices to be avoided. Such stacks pose serious transient voltage division problems often resulting in overstress of individual devices and consequent premature failure.



CHARGE LINE AND TUBE ASSEMBLY

FIGURE 3

The two grids of the chosen type of thyratron perform two different functions, the essentials of which are described in the manufacturer's literature.[4] In these generators both grids are pulsed and no dc priming current is used.

To achieve sufficient ionization in the first grid - cathode region the drive to the first grid is produced by four power MOSFETS having a 15 amp peak current rating, and operating effectively in parallel. The output pulse from these is transformer coupled to the first grid, the turns ratio being chosen to achieve a sufficiently rapid built up of current while still maintaining adequate drive current when the thyratron becomes fully conductive.

The trigger pulse to the second (control) grid needs relatively little power and satisfactory results have been obtained with MOSFETS packaged in T039 and T0220 packages. To minimize jitter and drift a pulse of several hundred volts peak amplitude having a risetime of a few nanoseconds is desirable. Whilst this requirement can be met it is essential to ensure that there is adequate protective circuitry incorporated to prevent MOSFET failures due to high voltage spikes appearing at the thyratron control grid. It is inevitable that components included for this purpose will cause some degradation of risetime and pulse amplitude and compromise is necessary.

The techniques used have produced an overall jitter performance exceeding the specification with no failures to date attributable to spike feedback. Because the gas discharge in the first grid-cathode region takes some time to become fully established it is necessary to delay the control grid trigger pulse. A coaxial cable delay line has been used because of its stable delay properties, and this has enabled the drift specification to be met.

High Voltage Supply

The dc high voltage supply is provided by a rectifier tripler driven via a step up transformer from a high frequency switched mode power supply. The circuit includes regulators for voltage and current outputs and a fast acting one cycle SCR crowbar to protect active devices against arcs in the thyratron or accidental flashovers elsewhere.

Low and Medium Voltage Supplies

All dc to operational circuitry is obtained from well-regulated supplies. Higher voltage rails use MOSFET series regulators while lower voltage rails use bipolar and/or integrated circuit regulators. The +90 V rail required by the fiber optic unit is used for the first grid pre-driver stage and is a source of optional dc first grid priming current for other applications where its use is appropriate. A +300 V rail supplies the power MOSFET output stages for both first and second grid pulse generators.

Tube heater and reservoir supplies are of the switched mode dc-dc converter type incorporating current limiting and produce stable dc voltages to help minimize jitter and drift. A conventional power transformer with multiple secondary windings and associated rectifier/filters provides unregulated dc to the various regulators and dc-dc converters.

Mechanical Design

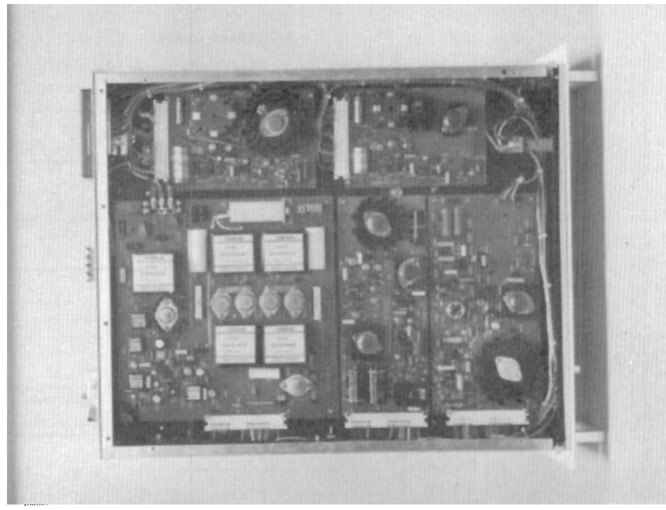
The main design constraints were a) minimizing overall size within the EIA rack mounting format, b) providing completely isolated ground systems for the generator circuitry and the external case, c) providing easy access for change of charge lines, and d) providing easy access to all printed board circuitry.

The solution adopted uses an inner metal tray upon which is mounted all functional circuits and the charge line housing, which also accommodates the tube (see Figures 3 and 4). The HV pulse output sockets are bolted directly to the charge line housing to provide a low inductance return path to the tube cathode. This tray and charge line housing assembly forms the internal ground and is fastened inside the outer case by isolating bushings. An insulating plate separates the output sockets and charge line housing from the outer case, which constitutes the external ground.

Fiber Optic Trigger

Because fiber optic technology is comparatively new, LLNL assumed responsibility for the trigger link to the pulse generator. Timing for the Pockels cell drivers originates in the MOR. An integrated electronics system uses the same 62 MHz signal generator to mode lock the optical oscillator and to drive fast triggers for the Pockels cells and other subsystems on the laser. These triggers emanate from the MOR over fiber optics. A high power laser diode is used in order to achieve the required subnanosecond jitter. High-speed digital circuitry allows variation of trigger timing with one nanosecond resolution.

A special optical receiver was designed for the Cardon unit which gave specified output levels over a wide range of optical power inputs. The design proved to be nontrivial, and some iteration was



BOTTOM VIEW SHOWING LOW-LEVEL CIRCUITRY

FIGURE 4

necessary. The final version relies on a fast GA-201 SCR, triggered by an EG&G FND-100 large area photodiode. Fast PNP buffers follow the SCR to provide isolated trigger and sync outputs. The resultant package is a small, shielded module which is fastened to the rear panel of the pulse generator.

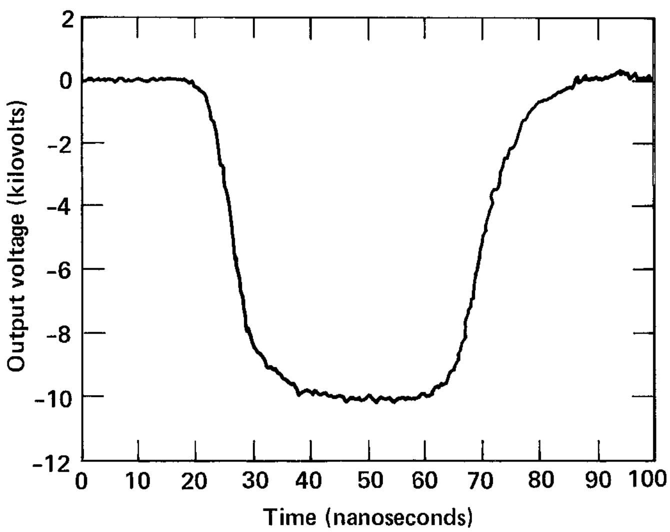
Equipment and System Performance

Nearly all the specification requirements have been met, the main exception being the risetime of the Model A unit. Indications at the time of writing are that this will lie between 3 nsec and 3.5 nsec rather than attain the specified figure of less than 3 nsec. The limitation on this parameter is the risetime of the thyratron.

The output pulse produced by the charge line and tube circuit has overshoot, ringing and tilt parameters well within specifications (see Figure 5). Moreover, pulse characteristics, other than width, are hardly affected by change of charge line assemblies.

The first application of the new driver has been in the Novette Laser Bay. Just a year after communication between LLNL and Cardon had been initiated, a prototype was installed on Novette. Its small size allowed the installation without removal of the previous in-house built driver. No special problems were encountered during the installation. The unit was configured with a 25 nsec pulse width. System timing was established by seeking the 10 pps master oscillator pulse with a downstream laser diagnostic. This pulse is visible only when it falls within the Pockels cell gate. Pockels cell driver timing was varied to pass that pulse, and, by smaller variations, the beginning and end of the gate were found. A simple calculation then allowed a final setting midway in the Pockels cell gate. Except for one failure on the prototype in circuitry which has since been modified for the production units, no system retiming has been necessary since installation.

We have now made extensive performance measurements in the laboratory on two units. We have seen some thyratron problems, possibly due to the rigors of shipping. These were manifested by high prefire rate and reluctance to hold off dc on the anode. In all cases a week or so of continuous pulsing at



OUTPUT PULSE WITH 50 NSEC CHARGE LINE

FIGURE 5

10 pps conditioned the tube into acceptable behavior. We will be burning in every unit in this manner, based on this experience.

We have made extensive use of the Hewlett Packard 5370A time interval meter to characterize the jitter and drift of these units. Once conditioned, the long term drift settles down to less than 100 picoseconds per week and the short term jitter over 1,000 shots is typically less than 100 picoseconds, one sigma (excluding jitter contributed from the fiber optic trigger).

We discovered that the prefire rate, without input triggers, could be as high as a few per minute, depending on the anode voltage and the particular tube being tested. Such performance is typical of hydrogen thyratrons with a dc anode potential near maximum rating and would not be acceptable for our large laser systems. Further testing fortunately showed that the prefire rate dropped to an almost unmeasureable level when the unit was pulsed at 10 pps. Under these conditions, an anomolous fire event occurred once every few hours, as well as we can measure. For the pulse widths used during these tests, the anode was at voltage for 50 - 80 percent of the time between pulses, so the effect cannot be attributed to reduced average anode voltage. Whatever its cause, it is a simple matter to operate the unit at 10 pps around shot time. Since life of the CX1588 has yet to be proven, we have also taken the precaution of removing the input trigger at other times. The high voltage is left on continuously during the two shifts of normal operation. Control of the triggers has been loaded into the computerized shot sequence, so the only manual operator action required is turning the unit on in the morning and shutting it down at night.

Conclusions

A joint effort between LLNL and Cardon has resulted in a new family of high-speed, high voltage pulse generators which will support the Nova laser system at Livermore. We acknowledge that development of the CX1588 and CX1599 thyratrons by English Electric Valve, Ltd. makes the required performance from these drivers possible and wish to thank Mr. Hugh Menown for his support over the past year.

Laser system performance requirements are being met by these new units with a level of reliability and operator compatibility not previously experienced. Such performance has become necessary as these systems proliferate and become even more complex than in the past.

We are continuing to explore high speed thyratron operation, both at LLNL and at Cardon. Improvement of Model A risetime performance is particularly interesting to the Laser Program and independent development of CX1599 based pulsers is being carried out at LLNL. Combining this technology with an electromagnetic shock line sharpener is of interest.[5] At Cardon, the 300 nsec trigger delay through the unit is a problem for other markets and is being addressed.

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