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Multiple-Circuit Pulse Generator for High-Repetition-Rate Rare Gas Halide Lasers

Prepared by C. P. WANG
Aerophysics Laboratory

15 March 1978



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MULTIPLE-CIRCUIT PULSE GENERATOR FOR
HIGH-REPETITION-RATE RARE GAS
HALIDE LASERS

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15 March 1978

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MULTIPLE-CIRCUIT PULSE GENERATOR FOR HIGH-REPETITION-
RATE RARE GAS HALIDE LASERS

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ABSTRACT

A multiple-circuit high-pulse-repetition-frequency (PRF) pulse generator for the pumping of rare gas halide lasers is reported. With this multiple-circuit design, high PRF can be achieved by the use of existing low PRF thyatron switches and capacitors. A two-circuit pulse generator was constructed, and its performance is described. By means of this pulse generator and a blowdown-type fast transverse-flow system, high PRF laser action in XeF was obtained; typically, 6 mJ/pulse at 1 kHz or 6 W average power. High PRF laser action in N₂ was observed also.

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I. INTRODUCTION

Recent advances in ultraviolet (uv) lasers, particularly the rare gas halide lasers, ¹⁻⁸ indicate that the high-power and high-efficiency laser radiation in the uv spectrum region can readily be achieved. Electric-discharge-initiated lasers in XeF with wavelengths of 351, 353, and 349 nm and in KrF with wavelengths of 249 and 250 nm have produced the greatest power and efficiencies. ^{6, 9, 10} Pulse energies of more than 100 mJ with overall electric efficiencies of more than 1% have been obtained in XeF and KrF lasers. ⁹⁻¹²

The significance of these electric-discharge-initiated rare gas halide lasers is the possibility of producing high-average-power lasers by means of higher pulse repetition frequency (PRF) than is possible with some form of electron-beam initiation. High-average-power uv lasers are important for such applications as laser isotope separation and nonlinear spectroscopy. Thus far, PRF's of 20 Hz without flow, ^{10, 15} 200 Hz with slow longitudinal flow, ^{10, 15} and 500 Hz with fast transverse flow ¹⁶ have been demonstrated.

Major requirements for a high PRF rare gas halide laser are a pulse generator capable of delivering fast current rise and a large peak current at a high PRF, and a fast-flow system to replace the gas after every discharge pulse. Note that, for relatively slow current rise and low peak current, thyatron switched circuits capable of more than a few tens of kilohertz PRF have been demonstrated. However, for the pumping of rare gas halide lasers, fast current rise, large peak currents

and low circuit inductance are necessary. So far, low inductance pulse generators with a grounded grid thyatron can be operated at only a few hundred to a thousand hertz PRF because of the difficulties of thyatron turn-off and recovery.¹⁶ Better control and higher PRF can be obtained by the use of a triple-grid thyatron (e.g., English Electric Valve, Inc. Model CX1535). However, the inductance of this thyatron is rather high, and its current rise too slow.

A pulse charging technique, with a tetrode tube used to isolate the charging supply from the thyatron during each pulse and to control the charging time interval and duty cycle, provides sufficient thyatron inter-pulse recovery time. This technique has been used to achieve a few kilohertz PRF.¹⁷ However, the tetrode and the controls are floated at high voltage, and the average power capability of this pulse charging technique is low.

Reported here is a novel multiple-circuit pulse generator for pumping high PRF rare gas halide lasers. Basically, it consists of many thyatron switched discharge circuits fed to a common transmission line. Each circuit is complete with charging resistor, storage capacitor, and thyatron switch and is triggered, in turn, as with a Gatling gun. The major advantage of this pulse generator is the use of existing low PRF thyatrons and capacitors to achieve high PRF output pulses with fast current rise, large peak current, and low circuit inductance.

As with the rapid gas-flow system, closed-cycle, fast-transverse-flow gas recirculation systems have been constructed for high PRF

CO₂ lasers^{18, 19} and rare gas lasers.¹⁷ A simple blowdown-type burst-flow system was constructed¹⁶ to demonstrate the principle and to study the performance of the multiple-circuit pulse generator. This burst-flow system is simple and flexible.

II. MULTIPLE-CIRCUIT PULSE GENERATOR DESIGN

High PRF laser action up to 500 Hz in XeF has been achieved by a thyatron-switched, low-inductance pulse generator.¹⁶ Further increases of the PRF are limited by the short charging time, the lack of thyatron recovery and turn off. For high PRF operation, it was found that there may not be enough reverse voltage on the thyatron to turn off the conduction because the charging current is so high and the circuit inductance is so low. Hence, the maximum PRF a single thyatron circuit can achieve is rather limited.

The use of two thyatrons in a LC-inversion circuit, which provides alternating polarity and twice the PRF, has been demonstrated.²⁰ A multiple-circuit pulse generator (Fig. 1) was conceived to further increase the PRF. It consists of N independent discharge circuits fed to a common transmission line.

For each circuit, D is a high-voltage diode to hold the high voltage. R_c and L_c are the charging resistor and inductor, respectively, and are used to limit the charging current and control the charging time. C_s is the storage capacitor, and S is a thyatron switch. Each circuit is connected to a common transmission line to minimize the circuit inductance. The equivalent line inductance and capacitance are L_T and C_T , respectively. The other end of this transmission line is connected to the electrodes. Since the electric-discharge pulse duration is much shorter than the time between pulses, each circuit, more or less, discharges independently.

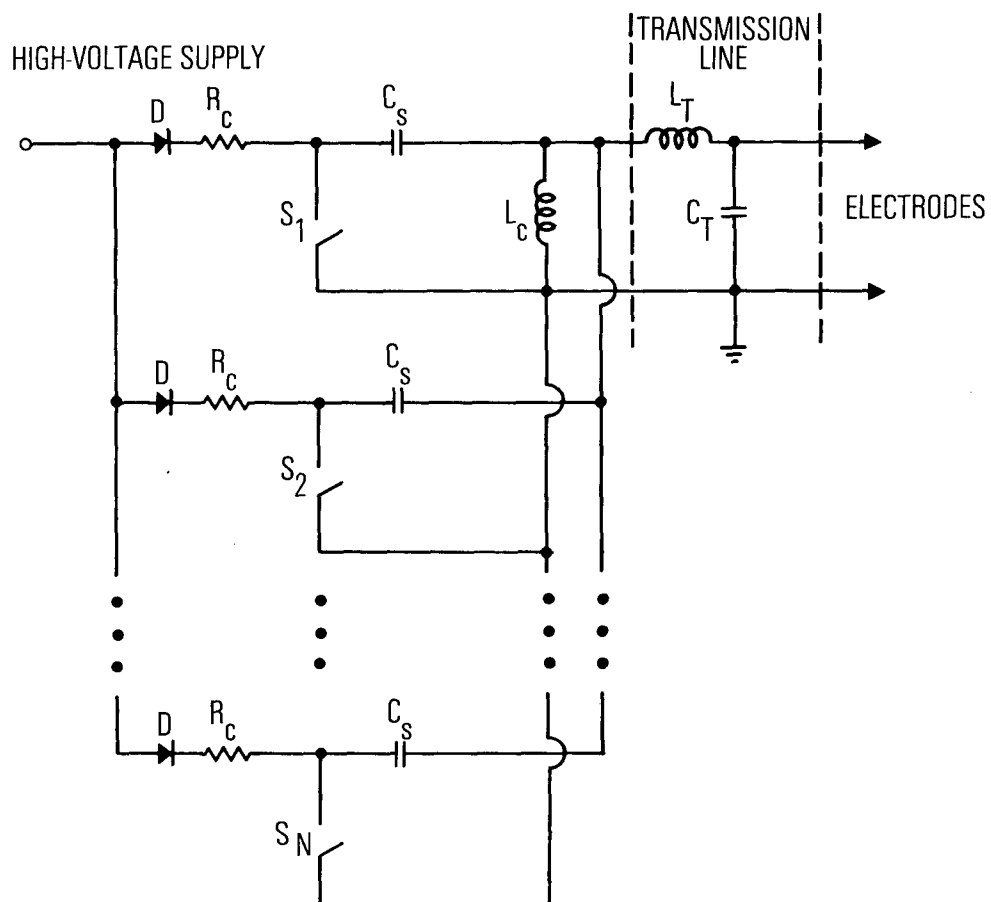


Fig. 1. Equivalent circuit diagram of multiple-circuit pulse generator

Each circuit is equivalent to a pulse discharging circuit, with a storage capacitor (C_s) and peaking capacitor (C_T). Because of the finite discharge breakdown time, the C_T is charged up before the gas becomes fully conductive. Hence, high current rise and high peak current can be achieved. For optimum operation, L_T is kept to a minimum, and C_T is kept to less than $C_s/2$.

Furthermore, the PRF of this pulse generator is N times the PRF of each circuit. The advantages of this multiple-circuit design are (1) the long charging time and long pulse separation time for each circuit, which ensures uniform energy storage and sufficient thyatron recovery, and (2) the suitability of the low PRF thyatron and capacitors for use in achieving high PRF operation.

III. EXPERIMENTAL SETUP AND RESULTS

A fast-transverse-flow system and high-repetition-rate, fast-electric-discharge circuits are needed in order to investigate high-repetition-rate operation of rare gas halide lasers. For simplicity and flexibility, a fast-flow system operated in a blowdown (i.e., burst) mode was constructed. Details of the flow system are described in Ref. 16. Briefly, a high-pressure gas supply tank, a low-pressure dump tank, and two nozzles were used to control the pressure and velocity in the laser cavity and to ensure steady-state operation for a period longer than 0.1 sec (Fig. 2).

The flow becomes supersonic within the first nozzle and then goes through a normal shock wave downstream of the nozzle. Hence, the flow in the laser cavity is subsonic. The flow, again, becomes supersonic in the second nozzle and expands into a large, low-pressure dump tank. The laser cavity velocity and pressure are determined by mass conservation.

The volumes of the gas supply tank and dump tank were 40 and 310 liters, respectively. The throat areas of the first and second nozzles can easily be varied in order to change the cavity pressure and velocity. For a typical run, the nozzles consisted of 28 holes (0.043-in. diam) and 24 holes (0.085-in. diam), respectively. For a gas supply tank filled with He at an initial pressure of 45 psia, the cavity pressure can reach a peak of 700 Torr. The cavity pressure history, measured with an Endevco 8510-5 pressure transducer, is shown in Fig. 3, where the vertical scale is 180 Torr/div and the sweep speed is 50 msec/div. The initial delay of

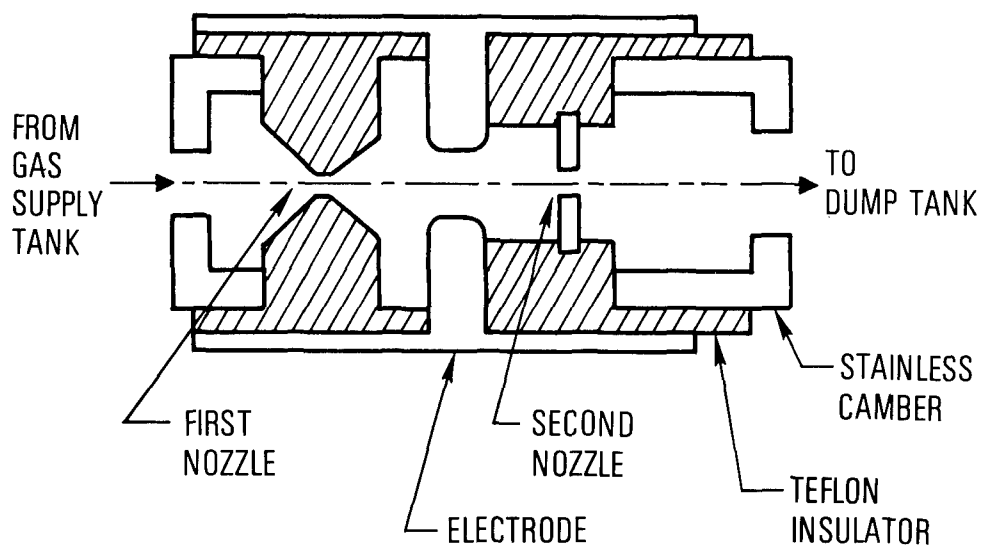


Fig. 2. Schematic of fast-transverse-flow system and electrode geometry

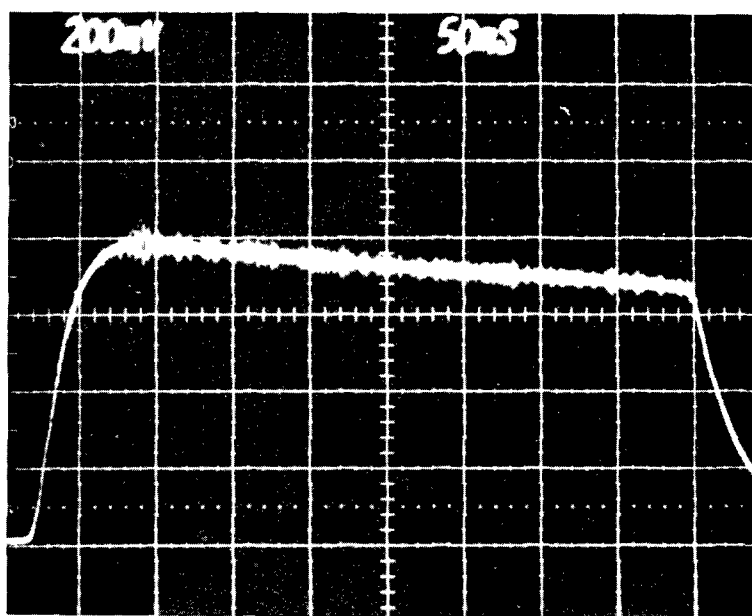


Fig. 3. Laser-cavity pressure history. Vertical scale = 180 Torr/div. Sweep speed = 50 msec/div.

pressure rise was caused by the valve opening time. As predicted by theory, the cavity pressure, after reaching a peak of 700 Torr, slowly dropped to 600 Torr in about 250 msec. Hence, a 250-msec testing time with a uniform pressure of about 650 Torr and a flow velocity about 14 m/sec was obtained.

As shown in Fig. 2, the discharge electrodes were made of brass with Teflon insulation. The flat region of the electrodes was 0.4 cm wide and 30 cm long with a 0.3-cm radius round-off on four sides. The electrode spacing was 1 cm, and the discharge volume was $1 \times 0.4 \times 30 \text{ cm} = 12 \text{ cm}^3$. The electrode spacing and shape can easily be varied for further optimization. The preionization flashboard, located near the second nozzle, consisted of 24 gaps with a 0.050-in. gap spacing. The distance between the preionization flashboard and the center-of-discharge region was kept at a minimum, about 2.5 cm. Reduction of this distance will cause arcing from electrodes to the flashboard.

A two-circuit pulse generator was constructed to demonstrate the principle and to investigate the performance of the multiple-circuit pulse generator. The storage capacitor was 20 nF, and the capacitance of the transmission line was 6 nF. Each circuit was switched by a EG&G Model Hy3202 grounded grid thyatron. Because of the low circuit inductance, the pulse width (FWHM) of the main discharge was about 40 nsec.

A similar circuit with a 7-nF storage capacitor and a 4-nF peaking capacitor was used for the preionization discharge. The pulse width (FWHM) was about 100 nsec. The time delay between preionization and main discharge was 700 nsec. Because of the low circuit inductance and fast

current rise, laser action in N_2 at 337 nm was observed. The maximum output energy was 2 mJ, about a factor of 7 lower than XeF laser output. The pulse width was 10 nsec or half of that XeF laser output pulse.

The two circuits of the pulse generator can be triggered independently with any preset time separation from less than 100 nsec to more than a few msec without any premature triggering or cross-triggering. Typical charging voltage traces (Fig. 4) indicate the independent triggering of the two circuits separated by 1.5 μ sec. The large high-frequency oscillation on the traces is the result of noise pickup from the fast discharges.

The control system consisted of a gate generator with variable delay and width, a signal generator (HP Model 214A), delay generator (Cordin Model 437-D), two trigger generators (EG&E Model TM-27), and two thyratrons (EG&E Model 3202). The gate signal was triggered by the opening of the supply tank valve. This gate signal was used to control the high-repetition-rate pulses generated by the signal generator. The high-repetition-rate pulses were then fed to the delay generator, where two trigger pulses with variable delay were generated for each input pulse. A pulse distributor was used to send the trigger pulses in sequence from the delay generator to various trigger generators. These trigger generators, in turn, triggered the thyratrons in the preionization and main discharge circuits.

For a typical run condition, the gate signal was delayed by 100 msec with a gate width of 30 msec, the repetition rate was set at 1000 Hz, and the time delay between preionization and main discharge was set at 700 nsec.

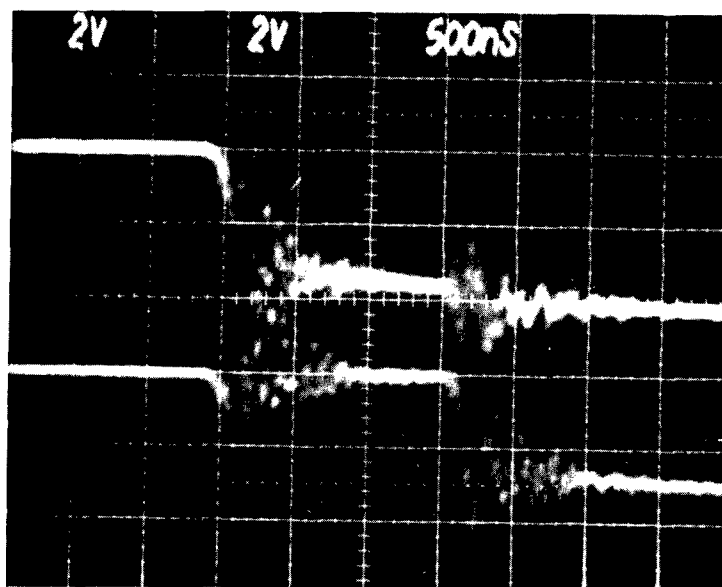


Fig. 4. Typical charging voltage traces of two discharge circuits separated by $1.5 \mu\text{sec}$. Vertical scale = 5 kV/div . Sweep speed = 500 nsec/div .

A stable optical resonator was used that consisted of a 10-m radius of curvature total reflecting mirror and a flat 50% reflecting mirror. The mirrors were separated by a distance of 53 cm and were internally mounted.

A lean mixture, $\text{He:Xe:NF}_3 = 1000:15:5$, was used in all of the experiment reported herein. The output energy was measured by a (Molelectron Model J3-05) energy meter with fine screen attenuators. For single-shot operation, a maximum output of 14 mJ/pulse was obtained with a charging voltage of 16 kV in a gas pressure of 700 Torr. This single-shot output was not optimized. The output continued to increase with increases in pressure and charging voltage. The single-shot laser efficiency (laser output energy divided by the sum of energies stored in the main discharge and preionization discharge circuit) was 0.5%. The output energy density (energy output per unit discharge volume) was 1.2 J/liter. Both the efficiency and output energy density can be increased by increasing the pressure and charging voltage and by the optimization of various other parameters, such as gas mixtures, electrode geometry, and output coupling.

The output pulse shape is shown in Fig. 5, which is a multiple exposure of 10 pulses. The variation of output intensity was less than 5%, and the average pulse width was about 20 nsec. The beam shape in the near field was the same as the cross section of the discharge region (0.4×1 cm). The beam divergence was about 3 mrad, indicating that the output beam contained high-order transverse modes. Without flow, a maximum PRF of 22 Hz was obtained, which agrees with earlier observations in a Blumlein-type fast-discharge device.¹³

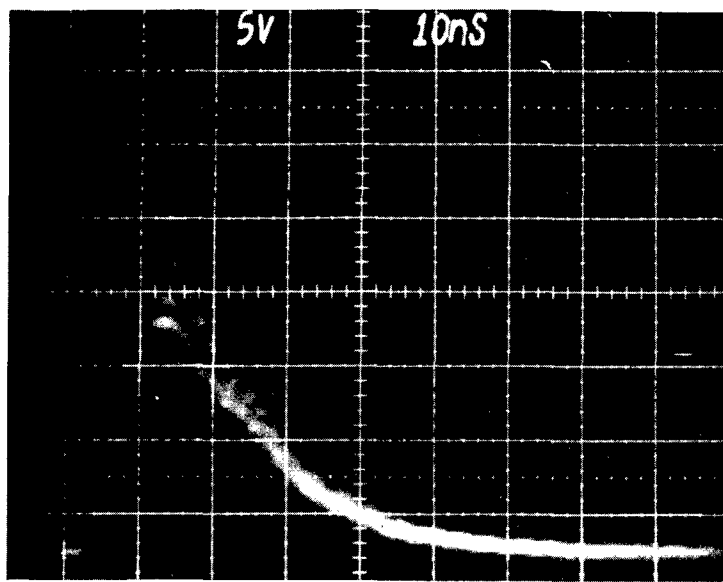


Fig. 5. Typical laser output pulse shapes (10 exposures). Sweep speed = 10 nsec/div.

With fast transverse flow, a PRF of 1000 Hz has been obtained. The cavity pressure and velocity during the discharge were 650 Torr and 14 m/sec, respectively. A typical oscilloscope trace of the charging voltages and the laser output energies is shown in Fig. 6. The upper trace indicates the charging voltage on one of the main discharging circuits (5 kV/div), the middle trace indicates the charging voltage on the preionization circuit (5 kV/div), and the lower trace indicates the energy meter output (4 mJ/div). The sweep speed was 1 msec/div. Because there were two circuits in the main discharge, the PRF of each circuit was one half that of the preionization discharge circuit. The output energy of each pulse varied somewhat as a result of nonuniform flow and a gas recirculating region in the laser cavity. A detailed study on the flow uniformity and acoustic waves in the cavity by means of a Zygo interferometer and pressure transducers will be reported later. The average energy measured was about 6 mJ/pulse at a PRF of 1 kHz, or an average output power of 6 W.

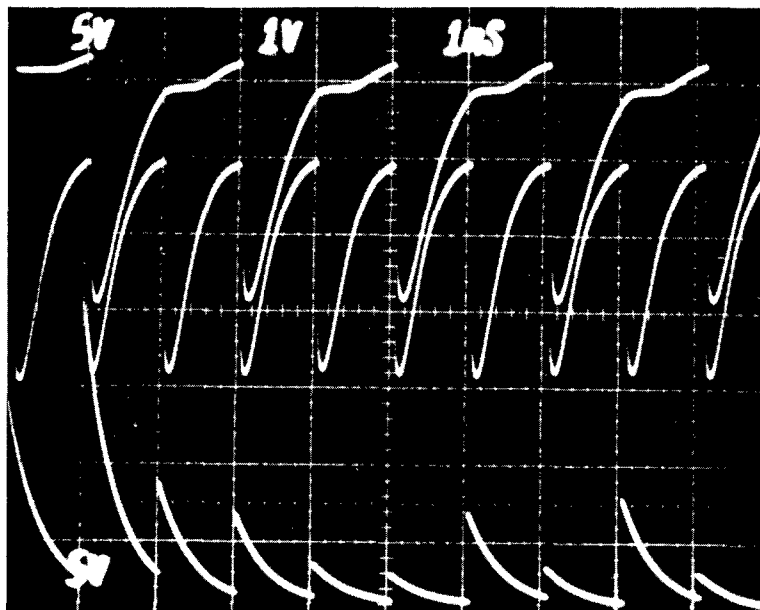


Fig. 6. Typical charging voltage traces of main and preionization discharges and laser output energies at 1000 Hz PRF. Upper trace = main-discharges, 5 kV/div. Middle trace = preionization-discharges, 5 kV/div. Lower trace = output energies, 4 mJ/div. Sweep speed = 1 msec/div.

IV. CONCLUSION

The reliability of a multiple-circuit pulse generator was demonstrated. A PRF of 1 kHz has been demonstrated. A PRF of several kilohertz can be achieved by the addition of more circuits to the pulse generator. Furthermore, it is possible to shape the discharge pulse by combining several independently triggered pulses to achieve long pulses with fast current rise and low circuit inductance.

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