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L.P. Bradley, E.L. Orham, and I.F. Stowers

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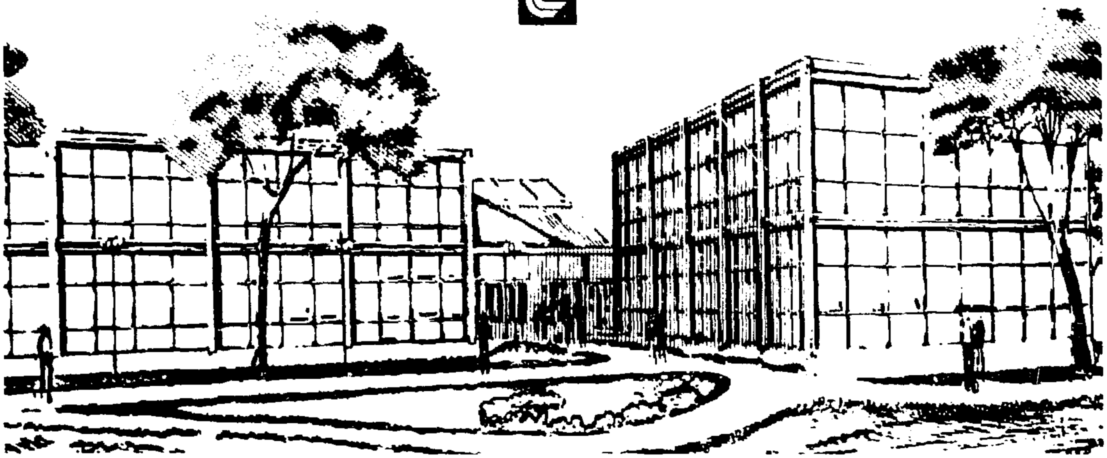

A COMPACT 5×10^{12} AMP/SEC RAIL-GUN PULSER FOR A LASER PLASMA SHUTTER*

L.P. Bradley, E.L. Orham, and I.F. Stowers
Lawrence Livermore Laboratory
P.O. Box 5508
Livermore, California 94550

ABSTRACT

We have developed a rail-gun plasma source to produce a plasma of 10^{21}cm^{-3} particle density and project it with a velocity of 3.9 cm/μs. This device will be used in a output spatial filter of Nova to project a critical density plasma across an optical beam path and block laser retroreflected light. The object of this paper is to describe the design of a pulser appropriate to the Shiva laser fusion facility, and to describe the preliminary design of a higher current prototype pulser for Nova the laser fusion research facility under construction at Lawrence Livermore Laboratory.

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Experimental Configuration for the Shiva Gun

The experiment is contained in a multiport vacuum chamber configured as a 20 cm aperture spatial filter with f/10 optics, as shown in Fig. 1. The wire which forms the plasma is located near the focal point of the optics, as shown in more detail in Fig. 2. The 3 mm long, 127 μm diameter aluminum wire is located between two electrodes in a 1 mm deep, 150 μm wide slot in a dielectric material. The slot constitutes a nozzle to confine the plasma during heating and to direct it across the optical beam path into a dump tank. Such a geometry increases the on axis density and reduces the leakage toward the optics.

The electrodes are connected via a low inductance parallel plate transmission line to the pulser. The pulser, containing 6 parallel Maxwell Type S, 0.22 μf capacitors is connected to the transmission line by 6 independent switches as shown in Fig. 1, and more detail in Fig. 3. The switches are midplane triggered, uv illuminated spark gaps[1] retrofitted into Tachisto 501 switch bodies. This trigger configuration is similar to that used in the Pulsar SW50K gap, but provides lower net inductance. The trigger is fed through the trigger pin and first arcs across to the illuminator which is connected to ground via a current limiting resistor. The small gap preilluminates the main gap and sharpens the trigger risetime. This provides nanosecond jitter with a rounded trigger pin and is not sensitive to erosion. An equivalent circuit (common also to the Nova pulser) is shown in Fig. 4. The pulser when charged to 50 kV provides a current rise time of 5×10^{12} a/sec. These main spark gaps, when triggered with a fast rising trigger pulse, provided nanosecond jitter and hence excellent current sharing of the parallel gaps and synchronization with the laser and diagnostics. When connected to the wire, including the large feedthrough inductance, the current has a quarter period of 300 ns.

Affect of Nonlinear Load

Initially while the wire is inertially confined, heating is resistive and follows a linear temperature variation. After burst, the resistance is characterized by a Spitzer resistivity. We conceptually distinguish two phases that dominate the plasma acceleration. A heating phase occurs near burst when the resistivity is high. Thereafter a JxB force increases the plasma directed velocity. By tailoring the current pulse history, we can to some degree separately control the plasma temperature and net plasma velocity, and thereby select both the divergence and closure time.

Experimental Results

The plasma velocity was determined by using streak camera photographs and a Faraday cup located 39 cm from the wire and axially centered on the plasma axis. Experimental results and a code[2] prediction for 20 kV charge voltage are summarized in Fig. 5. Such correlations of data and prediction reflect the present level of design.

Nova Pulser Design

We require a critical density plasma to obscure a 6 mm diameter region with a closing velocity appropriate to a shutter to target distance of 40 m. We conducted a parametric survey with the code to establish the prototype characteristics. We constrained the design such that all capacitors and switches must be standard elements within the state of the art and were thus able to concentrate on improving these elements to ensure reliability.

The prototype design contains 8 parallel 0.66 μf, 20 nH 50 kV capacitors connected through 4 parallel 10 nH rail gaps via a coaxial 3 nh vacuum feedthrough to the load. The total pulser inductance is 10 nh. This design is shown isometrically in Fig. 6 and in cross section in Fig. 7. The equivalent circuit is shown in Fig. 4. A logic signal is amplified by a Pulsepak 10A and transformer. A coaxial two stage Marx using the switch shown in Fig. 3 provides an output of 100 kV rising in 8 ns to trigger the rail gaps.

The rail gap shown in Fig. 8 has semirogowski electrodes and a long graded trigger blade. The trigger pulse is fed through a peaking gap on the end with its spark located on axis with the rails, thereby preilluminating them. The switching gas is 20% SF_6 and 80% Ar. The function of the uv produced primarily in the argon is to provide free electrons and metastable states in the main gap region. These electrons help in initiating avalanches and streamers, and also cause precise closing[3] of the streamer. A segment of the Nova pulser has been extensively tested and characterized, and provides nanosecond jitter. With the dc charge voltage, it provides multichannel operation, a feature which is somewhat insensitive to rail edge sharpness, thus tending to maintain reliability with age. We are presently testing electrode materials including low lead brass, Schwarzkoph K25 tungsten and Poco AXF5QC and ACF10Q graphite to to reduce erosion and most importantly to minimize prefire.

The 0.66 μf, 20 kV capacitors developed by Maxwell for this application are similar to the Garching type, and have a plastic case with a parallel railheader. The internal construction is similar to the proven Sylac capacitor. Internal inductance is 20 nH and the expected life is 10^6 shots.

The dielectric is a semiconductor coated polyurethane elastomer being cast in the shape required for the coaxial feedthrough. The effect of surface corona is minimized by employing a semiconductor coating; the uncoated polyurethane minimizes tracking under switches and capacitors. Its elastic behavior will restore its shape and in particular its contact with the conductors after magnetically induced deformations. The coaxial design minimizes the number of high voltage edges.

The pulser is housed in an electromagnetic shield and filled with atmospheric pressure SF_6. Two trigger generators located in the shield provide via separate peaking gaps a redundant trigger pulse to each blade.

Conclusions

We have developed and are continuing to develop reliable, low inductance, high current pulsers having nanosecond jitter. All spark gaps use uv preillumination to pulse sharpen the trigger, to minimize jitter, and to minimize the effect of electrode erosion with age. The systems are coaxial to minimize inductance and edge effects. A semiconductor coated elastomer dielectric minimizes surface corona and tracking.

These pulsers are utilized with a rail-gun to propel a high density plasma to a high velocity.

Acknowledgements

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References

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PLASMA SHUTTER EXPERIMENTAL CONFIGURATION

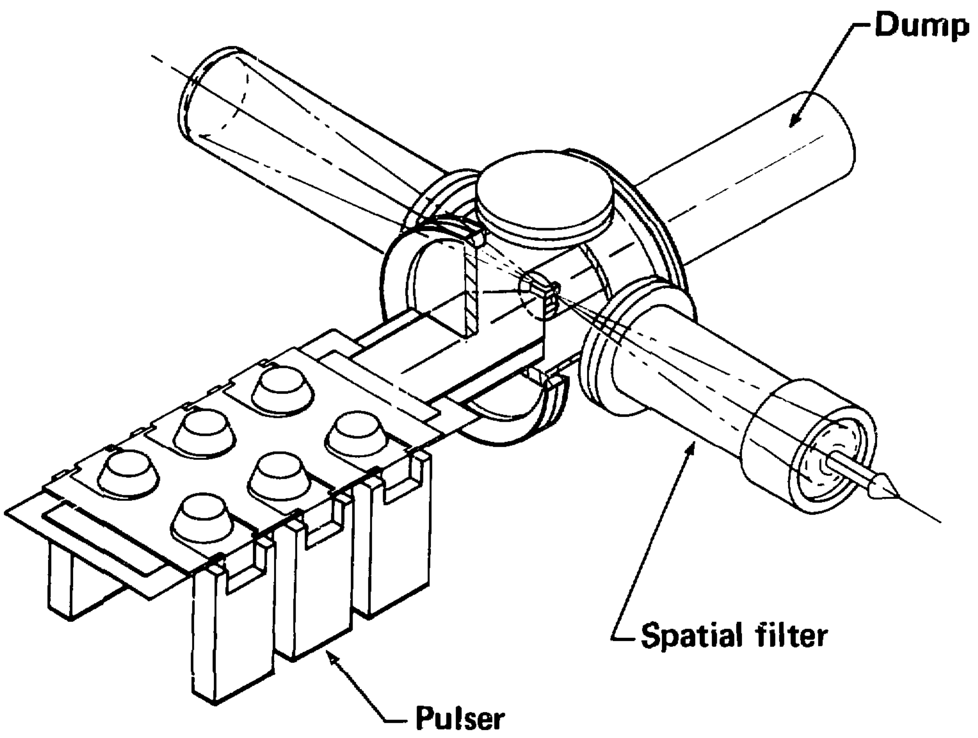

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Fig. 1

PLASMA GUN GEOMETRY

Plasma collection geometry

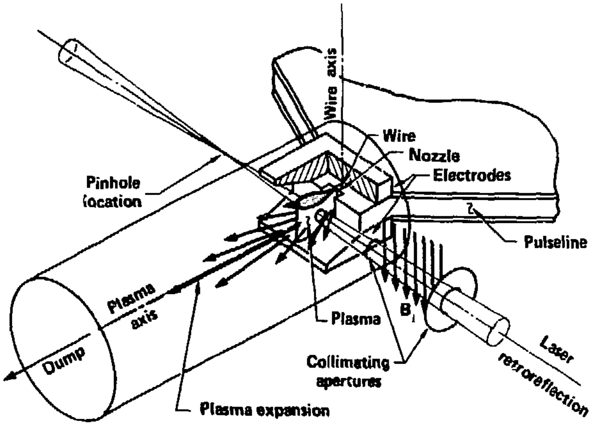

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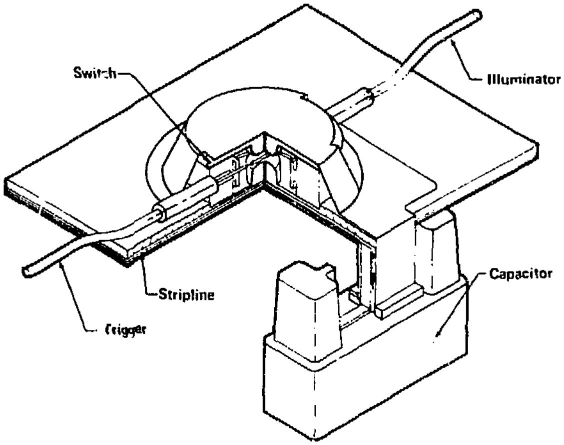
Fig. 2



1 ns JITTER, LOW INDUCTANCE SWITCH GEOMETRY

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Fig. 3

EQUIVALENT CIRCUIT OF PLASMA GUN AND TRIGGER

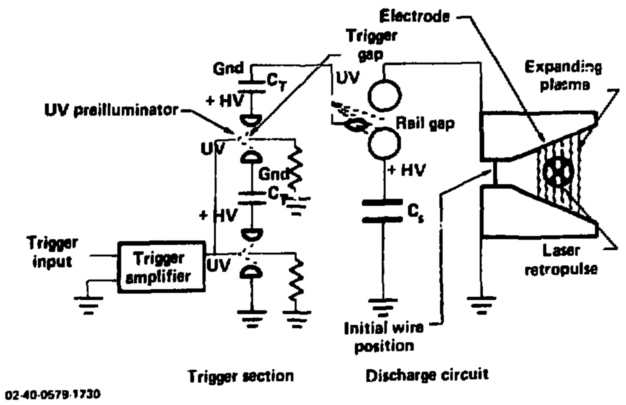

Fig. 4

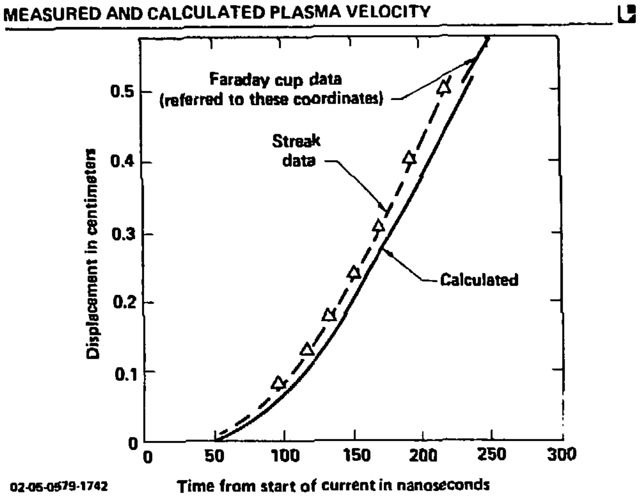
MEASURED AND CALCULATED PLASMA VELOCITY
Faraday cup data
(referred to these coordinates)
Streak
data
Calculated
Displacement in centimeters
0
0.1
0.2
0.3
0.4
0.5
0
50
100
150
200
250
300
Time from start of current in nanoseconds
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Fig. 5

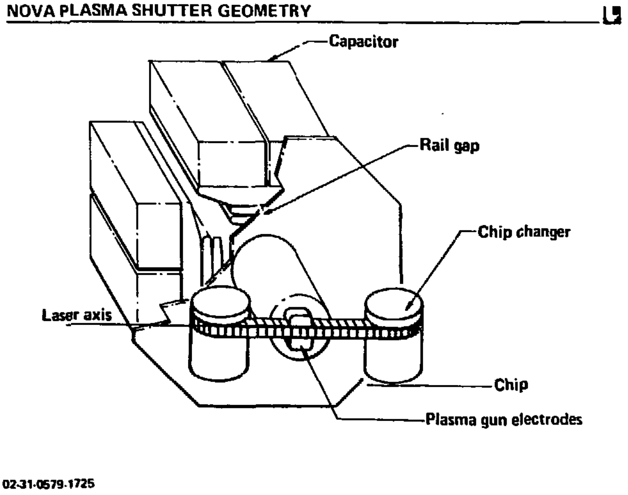
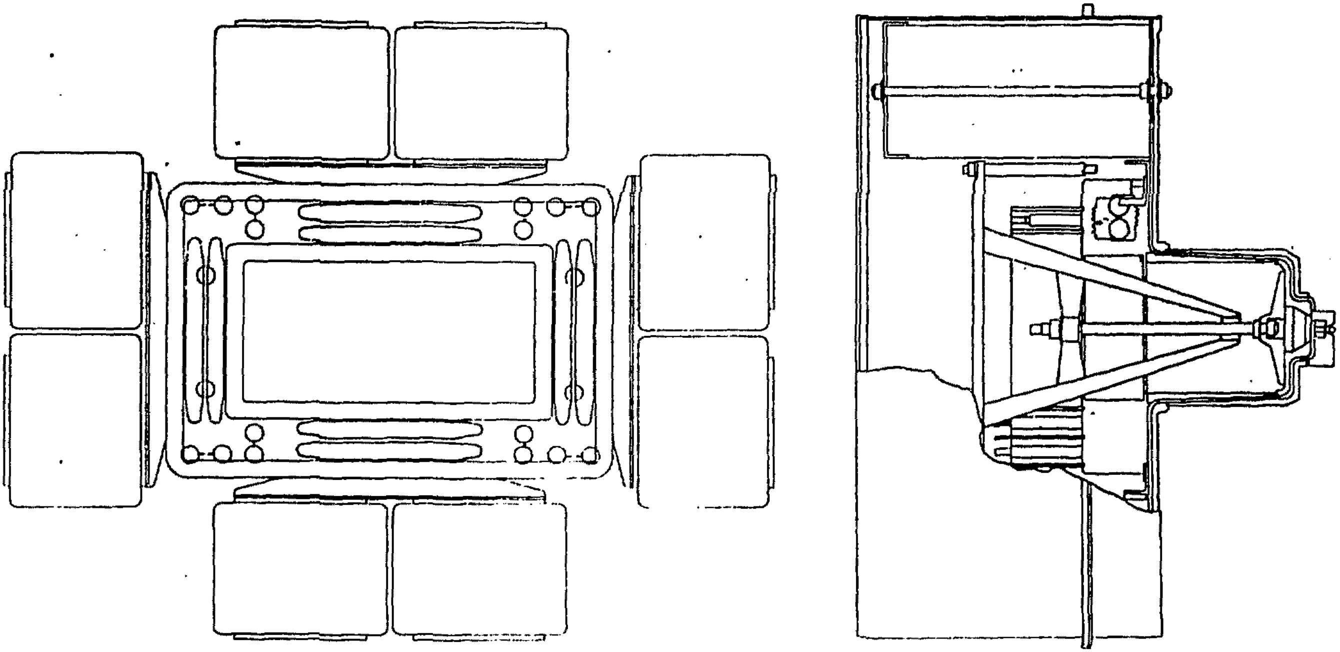

NOVA PLASMA SHUTTER GEOMETRY
Capacitor
Rail gap
Chip changer
Laser axis
Chip
Plasma gun electrodes
02-31-0579-1725

Fig. 6

PLASMA SHUTTER PULSER CROSS SECTION



Back view

Side view

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Fig. 7

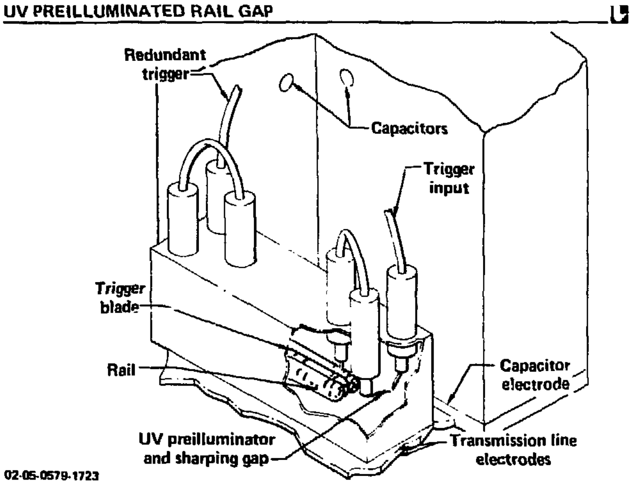
UV PREILLUMINATED RAIL GAP

Fig. 8