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ELECTRIC DISCHARGE CHARACTERISTICS OF CABLE PFN USED AS A PUMP*

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Abstract

The cable pulse forming network (PFN) is an excellent pump for transverse discharge lasers. The effect of load characteristics on PFN design is discussed in detail. Experimental results are presented for a rare gas halide laser pumped by a cable PFN.

Introduction

Many pulsed laser systems require a pump capable of depositing the stored energy in a time comparable to the laser pulsewidth. For rare gas halogen (RGH) systems the pulsewidths are typically a few tens of nanoseconds. One type of pulse forming network (PFN) very well suited to this service is the co-axial cable PFN.

In order to design a PFN a few assumptions have to be made about the load. A typical transverse discharge RGH laser will have a breakdown voltage of 40 kV and an impedance of 1 ohm or less. For best laser performance the voltage on the laser should have a rate of rise (dV/dt) of 500 V/nsec or greater. The load inductance including connections to the PFN must be kept low (< 10 nH) in order to deliver the stored energy in 30 nsec.

The cable PFN shown in Fig. 1 meets these requirements quite well. The storage capacitor C_s is initially charged to a voltage V_o. On closure of the triggered spark gap switch S, the cable PFN begins charging through the interconnection inductance L_d. For charging times somewhat longer than the electrical length of the cables, the PFN can be treated as a single capacitor (C_c) of value

$$C_c = \frac{\tau}{Z_o} \qquad (1)$$

where τ and Z_o are the one-way transit time and the characteristic impedance of the cable PFN. The voltage on the cable can be approximated by

$$V_c(t) = Vm\ (1-\cos \omega t) \qquad (2)$$

where the ringing frequency is calculated from

$$\omega = \frac{1}{(L_d C_{eq})^{1/2}} \qquad (3)$$

where L_d is the inductance of the driver and the equivalent series capacitance is expressed by

$$C_{eq} = \frac{C_s\ C_c}{C_s + C_c} \qquad (4)$$

where C_s is the capacitance of the storage capacitor and C_c is the cable capacitance. Since the charge divides between series capacitors, the peak voltage is expressed by the formula

$$Vm = V_o\ \left(\frac{C_s}{C_s + C_c}\right) \qquad (5)$$

where V_o is the initial voltage on the storage capacitor. It is worth noting that if $C_s >> C_c$, the ringing frequency is determined by primarily C_c and L_d. Also, if the voltage is allowed to ring to its full peak value ($\omega t = \pi$ radians) the voltage will nearly double. The time rate of change of voltage on the cables can be found by taking the derivative of equation (2) and is expressed as

$$\frac{dV}{dt} = V_m\ \omega \sin \omega t \qquad (6)$$

which can be used to find the current in the switch

$$I_s = C_c \frac{dV}{dt} \qquad (7)$$

When the laser reaches breakdown the load current

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will be approximately

$$I_1 = [I_{PFN} + I_s]\ [1 - \exp(-\frac{R_1 t}{L_1})] \qquad (8)$$

where L_1 is the load inductance, R_1 is the load resistance, and the current due to the PFN is

$$I_{PFN} = \left[\frac{V_{bd}}{R_1 + Z_o}\right] \left[U(t) - U(t - 2\tau)\right] \qquad (9)$$

where V_{bd} is the breakdown voltage and the unit step functions specify a rectangular pulse of width 2τ.

Experimental Results

Several PFNs of this type have been used at LASL with excellent results. The following data are taken from one typical laser system. The laser discharge cross section is 12 mm x 19 mm which results in a 138 cm^3 volume over the 0.6 m electrode length. A gas mix of 3.05 torr F_2, 55 torr Kr, and 3150 torr He was used. The PFN consisted of 48 parallel coaxial cables (Essex 40/100) of 2.44 mm length. This results in an impedance (Z_o) of 0.63 ohms and a one-way transit time (τ) of 15 nsec. Laser inductance was estimated at 8 nH. The electrical driver was a two-stage Marx generator having a capacitance of 150 nF per stage charged to 48 kV DC. The inductance of the driver (L_d) was calculated at 275 nH.

The resulting voltage and current waveforms are shown in Fig. 2. The voltage rises to 42 kV breakdown in 80 nsec. At that time the current begins to flow and reaches 62 kA in 36 nsec. Figure 3 shows the resultant power and energy curves. Power is calculated from the instantaneous product of voltage and current, and energy is the time integral of the power. The ratio of voltage to current provides the time varying impedance shown in Fig. 4. The powe delivered by the PFN is 1.3 x 10^9 W in a 32 nsec FWHM pulse. This results in an energy deposition of 40 J during the pulse. The laser delivered an energy of 580 mJ per pulse in this configuration. The laser impedance during the pulse varies from infinite (just before breakdown) to near zero at the end of the pulse, which is probably the result of an arc.

A considerable effort has been devoted to studying the time varying resistance and its effect on PFN design, but the results are outside the scope of this paper.

Summary and Discussion

The cable discharge PFN has been discussed in detail, both in the charging and discharging modes of operation. Experimental results presented show this type of PFN is well suited to the generation of multi-gigawatt pulses in low impedance loads, even when the impedance varies with time. Experiments are in progress as LASL to design lower impedance higher power pFNs capable of pumping RGH lasers.

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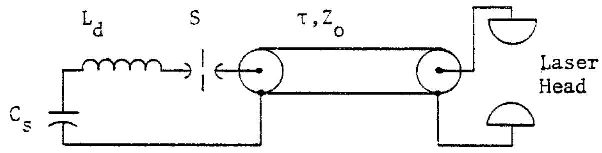

Figure 1. Schematic of Cable PFN

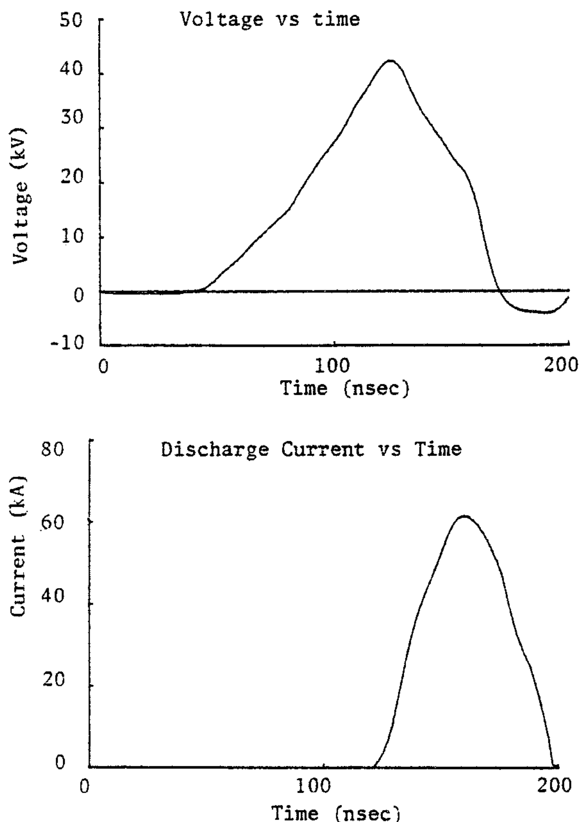

Figure 2. Laser Voltage and Current

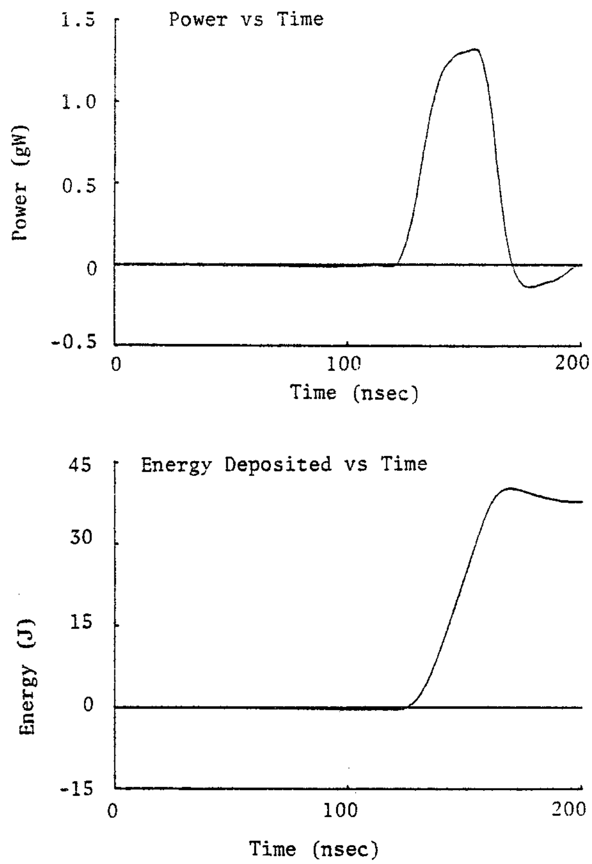

Figure 3. Instaneous Power and Energy Deposited

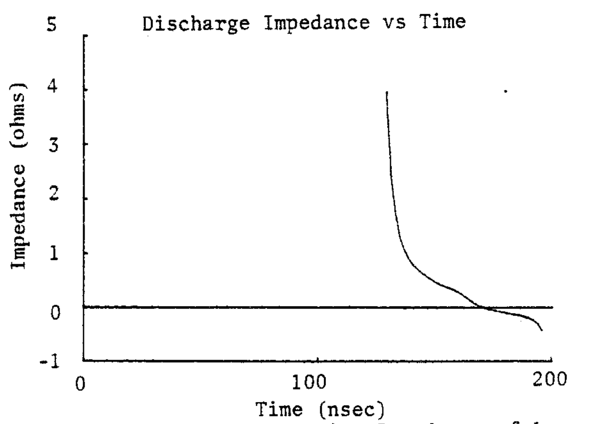

Figure 4. Time Varying Impedance of Laser