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COMPACT ELECTRON ACCELERATOR FOR PUMPING GAS LASERS

by

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ABSTRACT

We describe the design and application of a simple e-beam generator for the repetitive pulse pumping of gas lasers. The circuit uses a low inductance Marx and series tuned pulse forming elements.

Introduction

We describe the development of a compact electron accelerator for research into pumping a new generation of visible and UV gas lasers.[1] Recent development of the rare gas halide[2] and other lasers has provided a direct motivation for developing simpler, more flexible, and more economical e-beam sources. We describe such a source with emphasis on the Marx-PFN design.

The kinetics of the laser and its intended use[3] place direct requirements on the design of the pump e-beam source. Most lasers require uniform pump energy density. Also the lifetime of the anode foil separating the e-gun and laser cell is of prime concern. The pump pulse width is typically determined by the excited state lifetime of the lasing specie; for certain lasers it can exceed this lifetime. To obtain an inversion and extract reasonable power, the laser kinetics and energetics demand a minimum pump power density. Furthermore, most applications require high efficiency, economy of construction, and a reasonable rep-rate.

The laser requirements can be translated directly into source design parameters. The uniform pump energy density implies that we require a constant voltage pulse with fast rise and fall, the electron kinetic energy determining the depth and distribution of pump energy into the gas. Such a pulse is consistent with a long foil lifetime provided the voltage is constrained to be greater than 200 kV, because at lower voltages a significant fraction of the energy is deposited in the foil. Many lasers of interest today can be pumped with a pulse from 100 nsec to 1 μsec. Current densities[4] in general will not exceed 150 A/cm^2. Additionally, in any repetitively pulsed system the current density is constrained[5] by the foil survival and generally must average less than 1 mA/cm^2. High efficiency demands that the source be closely matched in impedance to the e-gun. Rep-rates of interest vary depending upon application. For research they might be 1 Hz or lower; for laser fusion applications ~100 Hz, and the photochemical and isotope separation schemes $\gtrsim$ 1 kHz.

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Due to the established (albeit relatively separate) technologies of Marx generators and PFNs, this approach was chosen for the desired source. We note that such systems have been constructed at higher voltage[6], but they are not compact.

Circuit design

We describe and contrast two Marx generators - one a coaxial Marx using barium titanite capacitors; the other a rectangular tray Marx using Aerovox high rep-rate capacitors.

The coaxial 8-stage PEBS Marx (Pulsed Electron Beam Source) was acquired from Ion Physics Corporation.[7] This Marx is a standard design developed some time ago and for example, used by Kubota[8] for an electron ring injector and by Ault[9] for pumping gas lasers. PEBS has a total energy of 200 J at 65 kV stage charge, a characteristic impedance $\sqrt{L/C}$ of 26 ohms and a characteristic half period $\pi\sqrt{L \cdot C}$ of 120 nsec. The PEBS Marx was originally designed for industrial processing. We modified it by changing the trigger system, vacuum system and diode. The re-configured Marx is triggered from a Pulsepak 10A. A master gap triggered by the Pulsepak fires the first three stages of the Marx and the remaining five stages are overvolted. The centrally located switches in the Marx stack are UV coupled by reflections from the interior wall of the aluminum housing. Very careful setting of the gap spacings permits us to operate this system with 1 nsec jitter. A view of the Marx and diode is shown in Fig. 1. The outer cylinder of the Marx is removed to show the interior construction of the Marx. The stages are separately assembled and cantilevered from one end of the housing with tie rods, such construction provides compactness but makes maintenance difficult.

The Vigil Marx generator that we constructed at LLL is shown in Fig. 2. It is an 8-stage Marx generator with 200 joules and 50 kV stage charge. It has characteristic impedance of 30 Ω and half period of 230 nsec. All stages are triggered using Pulsar gaps with nsec jitter. The Pulsar gaps utilize field distortion and simultaneous UV illumination. The use of parallel capacitors in each stage and folded metal plate feedback between stages provides low inductance and permits the identical construction of each stage on independently removable trays. Both Marxs are gas insulated. However, in the PEBS Marx the gas insulation determines the switching characteristics as well as the insulating properties. As a result, some problems from corona lead to occasional pre-firing. In the Vigil Marx the switch gas is independent of the insulating gas; additionally, adequate room is provided for PFN sections.

The basic Marx circuit is represented by a lumped capacitor and inductor with a switch coupling it to a load as shown in Fig. 3. Such a Marx has a characteristic impedance $Z_0 = \sqrt{L/C}$ and a characteristic half period $T_h = \pi\sqrt{L/C}$ when switched onto a matched load. Shown in the figure are three typical modes of operation for such a Marx. The very underdamped case produces a fast L/R rise and long decay voltage across the load; in this mode the Marx is typically crowbarred to determine the pulse length. Critically damped Marx produces a rise time determined by $\frac{L}{R}$ and a decay time determined by RC. The Marx matched to the load produces the highest power.

The circuit concept for generating a rectangular pulse was developed by Guillemin in the 1940's for radar applications. In this approach, a constant voltage pulse is approximated with a parabolic rise and fall. This provides rapid convergence of the Fourier series and requires fewer terms. By analogy each Fourier term may be represented by an LC section in a ladder network, as shown in Fig. 4. The LC values are determined from Eq. (1).

$$\frac{V(t)}{R} = \sum_{\nu=1,3,5..}^{n} V_0 \frac{b_r}{Z_n} \sin \frac{\nu\pi}{\tau} t = \sum_{\nu=1,3,5} V_0 \sqrt{\frac{C_\nu}{L_\nu}} \sin \frac{t}{\sqrt{C_\nu L_\nu}} \qquad (1)$$

where $$C_\nu = \frac{Z_n \tau}{\nu\pi b_\nu} \; ; \quad L_\nu = \frac{Z_n \tau}{\nu\pi b_\nu} \; ; \quad b_\nu = \frac{4}{\nu\pi} \left(\frac{\sin \frac{1}{2}\nu\pi a}{\frac{1}{2}\nu\pi a} \right)^2$$

Such a ladder network thus derived does not lend itself to practical construction. Since the ladder network is a linear passive circuit, it may be transformed into other physically realizable circuits. Of particular interest to us is the Foster transformation into a type A circuit as illustrated in Fig. 5. We use this circuit with a Marx tuned to the fundamental, and resonantly tuned circuits coupled to the Marx. The output voltage for two and three section examples of the type A circuit is shown as calculated using the SCEPTOR circuit code;[11] these outputs are reasonable approximations of a constant voltage pulse. For the two section case, "a" in equation (1) is .33, and the three section case "a" is .25. Increasing the number of sections for fixed Marx values increases the matched impedance. The two section case has an impedance of 1.4 Z_o and the three section case an impedance of 1.7 Z_o.

The voltage across the individual sections and the load of a three section PFN is shown in Fig. 6. The sinusoidal quality of the voltage across the second and third stage is characteristic of the Fourier series derivation. Note that peak voltages of only about 30% of the erected Marx voltage appear across the second section.

For situations where impedance drop during the pulse is significant, the PFN output voltage can be increased in time by increasing the impedance of the second section. This option has been used on the PEBS Marx.

The use of the SCEPTOR code also permits us to include elements which are non-linear, and include strays; the inclusion of both effects would make analytic solution difficult. We measured the variation of barium titanite capacitance with applied electric field. Such variation must be included in a description of the circuit if one is to properly model it.

Experimental results

Fig. 7 shows a comparison (including the voltage dependent capacitance) of the predicted output voltage wave form for the three section Vigil tuned to produce a 250 nsec FWHM pulse and driving a constant resistance 50 Ω load. Super-imposed on the wave form are the measured data.

We now consider coupling the diode to the Marx-PFN circuit. The diodes we consider herein use a cold cathode (razor blade). Such cathodes emit electrons from a plasma formed by exploding whiskers[12] at the cathode surface. The gap closes because of the plasma expanding at ~2 cm/μs. Such closure affects both the space charge limited impedance variation with time and the maximum pulsewidth.

A cross section of the PEBS diode and cell is shown in Fig. 8. Super-imposed on the figure is a numerical prediction of the electron trajectories in the diode and the associated current density at the foil plane. This predicted value is experimentally measured using a passive dosimetric technique.[13] We measure the time variation of the current density with a Faraday cup. The rising current pulse is characteristic of a constant voltage pulse across a decreasing impedance. Using these data and the geometry of the laser cell, we determine the deposited e-beam electron energy density throughout the cell with a three-dimensional electron deposition code.[14] Laser data obtained from this system are correlated with these e-beam source data using a kinetics code.[15]

Conclusions

The compact Marx-PFN e-gun system we have described has several attributes. We use a low inductance Marx which determines a minimum output pulsewidth. We produce constant voltage pulses by adding series tuned section to the Marx. The Type A approach is attractive because it uses minimum element voltage. The series sections described herein are about the size of a coffee mug. Sets of series sections and inductances when added to the basic Marx provide various output pulsewidths. We hold the Marx capacitance constant and simply change the small lumped PFN add-on sections. This procedure provides a constant total pump energy and constant pump energy density for a variable pulsewidth. This basic system has served as a flexible research tool.

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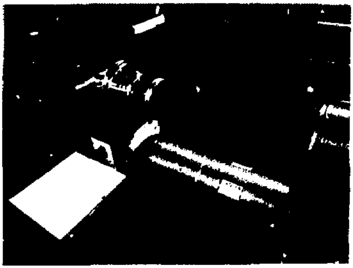

Fig. 1 PEBS Marx with aluminum housing removed.

Fig. 2 Vigil Marx

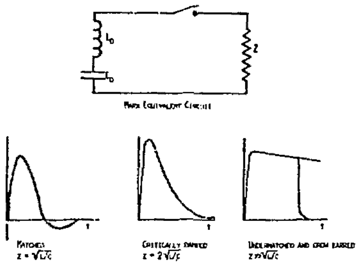

Fig. 3 Load voltage for Marx with several loads

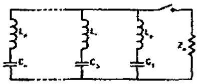

Fig. 4 Guillemin ladder network

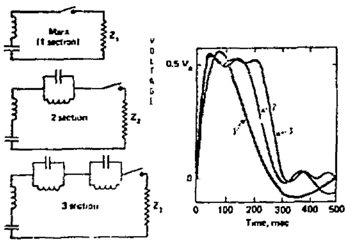

Fig. 5 Load voltage for 1, 2, 3 section PFNs

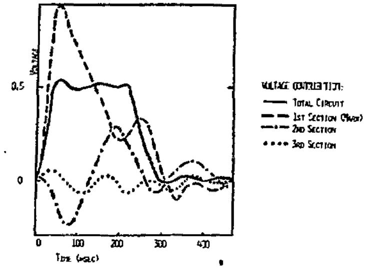

Fig. 6 Contributions to load voltage for a 3 stage PFN

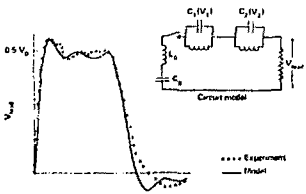

Fig. 7 Load voltage for 3 stage Vigil PFN

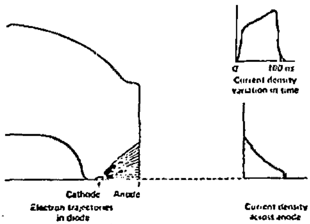

Fig. 8 PEBS e gun characteristics