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A RELIABLE THYRATRON-SWITCHED FLASHLAMP-PUMPED DYE LASER

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ABSTRACT

A thyratron-switched flashlamp-pumped dye laser capable of an average power of approximately 1 watt operating at 40 pulses/sec with a bandwidth of several GHz is described. The lamps are run in a high-current simmering mode to decrease lamp inductance and extend lamp life. In heavy use the laser system has proven to be very reliable with lamp lifetimes in excess of 10^7 shots and half-power dye lifetimes of better than 10^6 J/l for Rhodamine 6G.

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I. Introduction

Despite advances in laser-pumped dye lasers, flashlamp pumping remains an attractive way to obtain high average power from a simple, low cost laser system. There are many flashlamp-pumped dye laser designs in the literature, some capable of average powers in the neighborhood of 100 watts,[1] but a need still exists for a more modest dye laser with average power of about 1 watt which can be easily constructed from readily available components. This paper describes such a laser system, employing a thyratron switch to ensure reproducibe electrical pulses with a low temporal jitter and an improved aluminum-coated glass laser head which allows the double elliptical cavity to be flooded without deterioration of the reflecting surface. In addition, the technique of high-current simmering is introduced to both increase flashlamp lifetime and decrease the flashlamp inductance. Several laser systems have been constructed and have proven exceedingly reliable in over eight months of nearly daily use. Many features of this system should be directly transferable to other flashlamp-pumped lasers, e.g., the Nd:YAG system.

II. Laser Head and Dye System

The laser head consists of two linear xenon flashlamps of 10 cm arc length and 3 mm bore (ILC/L-2339) in a flooded, close-coupled, double elliptical cavity as shown in Fig. 1. The cavity, formed from a 28 mm diameter piece of Pyrex tubing blown into a heated carbon mold cut in the form of a double ellipse,[2] has been improved. Flow of the cooling water through the Pyrex cavity has been increased by joining a water exit tube (8 mm) to the ellipse as illustrated, and all edges are now fire-polished before the final annealing. An aluminum coating is evaporated on the outside of the double elliptical surface to provide a back-surfaced reflector that is impervious to attack by water ionized by the intense uv light of the flashlamps. Several Pyrex ellipses have been used in flashlamp-pumped dye lasers for over 1½ years (thousands of hours of running time) with no noticeable degradation in the reflecting surface. This technique will also apply to Nd:YAG lasers using double elliptical cavities since there is reason to believe that a silver coating on the reflector will couple significantly more light into the YAG rod than the traditional gold coating.[3] A detailed view of the seal between the Pyrex double ellipse and its supporting structure is also shown in Fig. 1: note the inside fillet of silicone rubber sealant (GE RTV-112) which forms a gasket that seals under water pressure. This seal becomes brittle after $\sim 10^8$ shots (possibly due to prolonged contact with the ionized cooling water) however the Pyrex ellipses can be made in large quantities and are easily replaced.

The dye cuvette is a thick-walled Pyrex tube 10 mm o.d. and 4 mm i.d. with the inside surface matted with #500 grit polishing compound to prevent whispering mode oscillations.[4] Although a quartz cuvette gives more than 50% increase in the energy per pulse for rhodamine 6G, the dye lifetime is increased by more than a factor of five when the Pyrex tube is used to filter out uv radiation below 300 nm. Stainless steel end plates bolt to the cavity supporting structure, providing compression for O-ring seals of the dye and cooling water and proper positioning of the flashlamps and dye cuvette windows.

The dye flow system, consisting of a 20 liter reservoir, pump, in-line filter, heat exchanger, and laser head, is designed so that the dye solution is in contact with only stainless steel, teflon, or polyethylene. The pump is a Micropump model 114-64-316 gear pump, and the filter is a

Millipore 5 μ pore, 142 mm diameter teflon filter. The dye is purged of oxygen by constantly bubbling dry nitrogen through the reservoir,[5] resulting in an estimated half-life for rhodamine 6G of over 10^6 Joules/liter, and allowing an effective running time of 60 hours with the 20 liter reservoir. More elaborate means of dye preservation, such as aluminum oxide filtering[6] or charcoal filtering have not been incorporated into the system yet. The heat exchanger consists of two coils, each 8 meters long of 3/8 inch thin walled stainless steel tubing, immersed in a water bath. The temperature of the dye solution and cooling water flowing through the tubing is measured to be within 0.3°C just before the dye enters the laser head.

A 7×10^{-5}M concentration of rhodamine 6G (New England Nuclear, Pilot 559) in a 2:1 mixture of distilled water and methanol is used as the active medium. Although concentrations on the order of 1.5×10^{-4}M yield higher laser pulse energies, the more dilute solutions give better beam spatial characteristics. The water/methanol mixture is preferred over pure ethanol since dn/dT (where n is the index of refraction and T is the temperature) is about a factor of three lower for the water/methanol mixture,[7] and the mixture has a heat capacity of nearly twice that of pure ethanol. Thermal distortion of the optical path along the dye cuvette causes broadening of the laser bandwidth; and for narrow (several GHz) bandwidth operation, the water/methanol mixture proves to be superior to an ethanol solution for repetition rates higher than 15 pulses/sec.

III. Electrical Circuit

The electrical circuit in Fig. 2 shows the principal new feature of this design: the use of the high-current simmering mode. The original simmering-mode operation of flashlamps by Jethwa and Schäfer[4] used d.c. currents of 0.03 - 0.10 A which resulted in substantial improvement in lamp lifetime and laser amplitude stability. However, such a small simmer current does not fill the bore of the lamp, but is seen as a thin filamentary discharge in the lamp. The high inductance of the thin plasma filament and the mechanical shock as the discharge expands to fill the entire lamp bore can be effectively eliminated by combining a pre-pulse discharge,[8] typically about 10% of the energy of the main discharge pulse, with the low-current simmering.[9,10] These circuits are, however, excessively complicated and require either "floating" switches (e.g., spark gaps) or a "floating" high voltage power supply if a cathode-grounded thyratron is used. It is possible to combine the low jitter, reproducibility, and reliability of thyratron switching with the performance characteristics of the pre-pulse/low-current simmer circuit by observing that a simmer current of approximately 0.5 A or higher will expand the filamentary discharge until it fills the entire lamp bore. In normal operation the lamps are run at 0.8 A with a voltage drop of 100 volts/lamp to guarantee stability during the main discharge pulse.

Simmering at 0.8 A does not seem to damage the lamp, and in fact, the lamp lifetime is increased to 10^7 shots (10^8 Joules input/lamp) at which point the light output decreases by a factor of two. Used lamps have a blackening around the cathode area, while most of the lamp's bore remains clear.

The main discharge circuit consists of a thyratron switch, an energy storage capacitor, and the flashlamps. The thyratron is a model 2506 glass hydrogen thyratron from EEV (equivalent to the EEV CX-1159) and a 0.2 μF, 25 kV low inductance capacitor (from either HiVoltage Components or Condenser Products) serves as the discharge capacitor C1. Energy is supplied to the discharge capacitor by the resonant charging circuit made up of an inductor L1, diodes D1, D2, D3, and capacitor C1,[11] where L1 is a 25 H inductor with an rms current rating of 0.5 A, and D1 and D2 are 0.5 A diodes with a PIV of 10 kV. Diodes D3 isolate D2 from the simmering circuit allowing a low impedance charging path for C1 through D2. Diodes D3 are Semtech SCS M6 diodes, PIV of 600 V, that have a negligible voltage drop even at several kiloamps peak current and have no noticeable effect on the speed of the discharge circuit.

The simmer current is produced by a constant current/constant voltage cross-over power supply (HP 6448B or homemade) capable of 1.5 A in constant current mode and -600V in constant voltage mode. (It is found that a 200Ω ballast resistor is needed when using the HP supply.) The simmer supply is isolated from the pulsed high voltage discharge by diodes D4 (Varo, VC70X, 1.5 A, 7 kV PIV) and a ~ 10 mH blocking inductor which is also the secondary winding of a trigger transformer. The simmer starting sequence proceeds as follows: the vacuum high voltage switch (ITT-Jennings rated at 50 A rms) is opened to protect diode D3, and a 500 V pulse from the discharge of a 0.5 μF capacitor is fed into the primary of the trigger transformer (primary 7 turns, secondary 250 turns wound on a 1 inch hypersil C-core). A 16 kV pulse from the secondary winding breaks down the lamps and a 0.1 μF capacitor charged by a small 4.5 kV power supply provides a slower, more sustained pulse that allows the simmer power supply to respond and continue the discharge. As a precaution should the simmer extinguish, the 4.5 kV supply is turned off before the vacuum switch is closed. The start-simmer procedure is partially automated and suitably interlocked to prevent breakdown of diode D3. Figure 3(a) shows the flashlamp light output for the laser under typical operating conditions, and Fig. 3(b) shows a typical laser pulse as monitored by an RCA 925 photodiode. Our RFI problems were eliminated by surrounding the laser head and discharge circuit in an aluminum box with RFI tee-filters on the high voltage power and thyratron grid inputs. Some improvements can be made to the circuit in Fig. 2. For example, a less complicated circuit to initiate the high-current simmer mode has been developed in recent months. Figure 4(a) indicates the new arrangement in which the first pulse from the main high voltage discharge overvoltages the lamps. This breakdown is sustained by the discharge of a 20 μF capacitor (initially at ~ -1500 V) until the simmer supply responds. The inductor L2 is the secondary winding of the previously used trigger transformer which is found adequate to block the main high voltage discharge pulse. Using three D3 diodes in series allows the vacuum switch to be removed from the circuit. Also, separate discharge paths (Fig. 4(b)) for each lamp are recommended to assure equal loading and allow faster discharge pulses. Although two constant-current supplies are needed in this case, only -300 V is sufficient in order to ensure a start of the simmering. Furthermore, the EEV 2506 thyratron (a surplus tube from a previous project) should be replaced by a lower inductance ceramic thyratron, e.g., EGG 1802.

IV. Results

Figure 5(a) shows the broadband laser output energy versus the energy discharged into the lamps, with a slope efficiency of about 0.4% above threshold. The derating of the laser output for higher repetition rates (Fig. 5(b)) is due mainly to the incomplete replacement of the dye in the cuvette before the next laser pulse. The laser resonator, defined by a high reflectivity spherical mirror with a radius of 6 meters and a 50% flat output coupler separated by about one meter, produces a 3 mm diameter beam with a 1.5 mrad full angle divergence. Interference filters and solid Fabry-Perot etalons were used to tune the laser and to narrow its bandwidth. Bandwidths of 15 cm^{-1}, 0.25 cm^{-1}, and 0.04 cm^{-1} were achieved using an interference filter (from Lambda-Physik) alone, an interference filter and a thin etalon (0.15 mm thick, 63% reflectivity from Lambda-Physik) and an interference filter, thin etalon and a thick etalon (10.0 mm thick, 20% reflectivity from Coherent Radiation), respectively. The laser output energy, relative to no tuning elements, decreases by about 10%, 25% and 50% in each of the three cases, for energy levels of ~ 20 mJ/pulse broadband output. At higher pump energies, the relative power loss due to the etalons is lower, but at the sacrifice of broader linewidths.

The beam quality allows the laser to be used as an effective pump source for an optical parametric oscillator and for frequency doubling in ADA. When pumping a CMX-4 IR accessory at the recommended input pump energies, we typically get a factor of two higher infrared pulse energies than manufacturer's specifications. Also, at 20 pps, a 12 mJ laser pulse will generate 1.5 mJ/pulse of UV light when focused with an f = 66 cm lens into a 5 cm long ADA crystal (Inrad, cut for 90° phase matching). Actually, substantially higher conversion efficiencies are possible with a tighter focus or higher pump energies, but conservative pump intensities have allowed approximately 1000 hours running time without damaging the doubling crystal. Under the above operating conditions, the second harmonic pulse energy stability $\sigma/\overline{E} \sim .04$, where $\overline{E}$ and σ are the mean energy and standard deviation of a large number of laser pulses. This corresponds to a pulse energy stability of the fundamental wavelength of about 2%.

V. Conclusion

A flashlamp-pumped dye laser system has been described which has high average power in a few GHz bandwidth. It was found that the use of high-current simmering greatly simplifies the circuitry required to have laser performance equivalent to pre-pulse/low-current simmering. The laser is easily constructed, has exceptional reliability, and has become a versatile laboratory instrument. The peak power of 10-50 kW and 1 μsec pulse make the laser useful for many types of nonlinear optics applications and experiments. Also, the system's high average power makes it useful for linear light scattering work, e.g., Raman scattering, in wavelength ranges not so readily accessible to CW dye lasers. Two such lasers were used in an experiment that required almost daily operation for over eight months, often continuously for 4 or 5 days at a time, without any failures.

We wish to thank Charles Sinclair and Mike Browne for introducing us to the thyratron switched-high current simmer circuit and for many helpful suggestions, Doyle Rogers for the loan of the hydrogen thyratrons, and Y. R. Shen and Eugene Commins for their support and advice. This work was partially supported by the Division of Materials Sciences, Office of Basic Energy Sciences, U. S. Department of Energy and the Division of Chemical Sciences, Office of Basic Energy Sciences, U. S. Department of Energy. One of us (S.C.) acknowledges the support of a National Science Foundation postdoctoral fellowship, #77-12322.

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Figure Captions

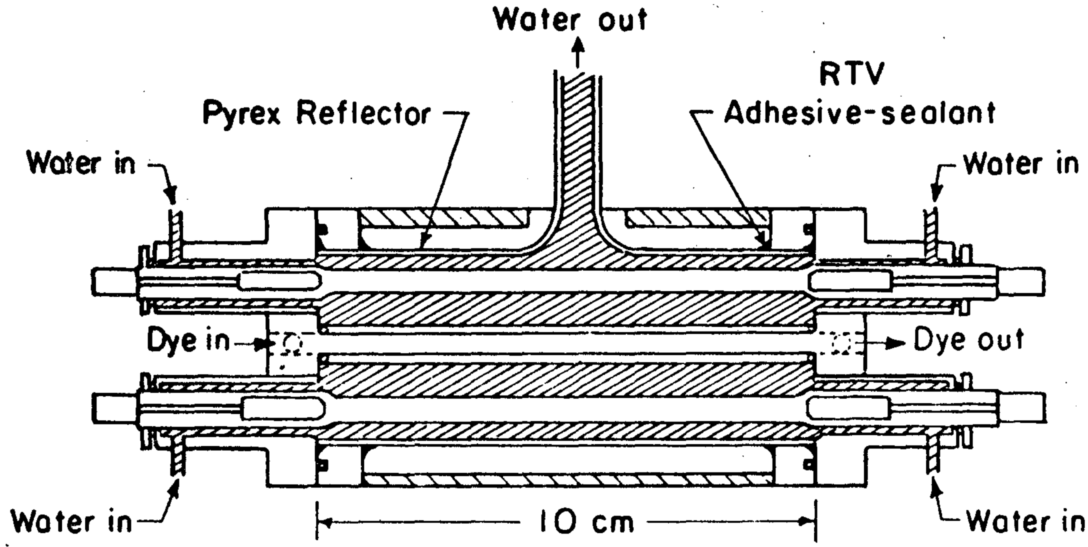
Fig. 1 Cross section of the laser head. A detailed view of the seal between the Pyrex ellipse and its supporting structure is shown in the lower right. Drawings are not to scale.

Fig. 2 Schematic diagram of flashlamp electrical circuit.

Fig. 3 (a) High voltage pulse across the flashlamps in the high-current simmer mode. (b) Laser pulse from photodiode monitor. Horizontal scale (a) and (b): 1 μsec/div.

Fig. 4 (a) Modified circuit diagram to simplify initiation of high-current simmer mode. (b) Possible arrangement to have separate discharge paths for each lamp.

Fig. 5 (a) Broadband laser output energy versus total energy input to flashlamps for Rhodamine 6G. ○ represent data taken with new lamps and dye; ● represent data taken near the end of useful lamp and dye lifetimes. (b) Degradation of laser output versus repetition rate.



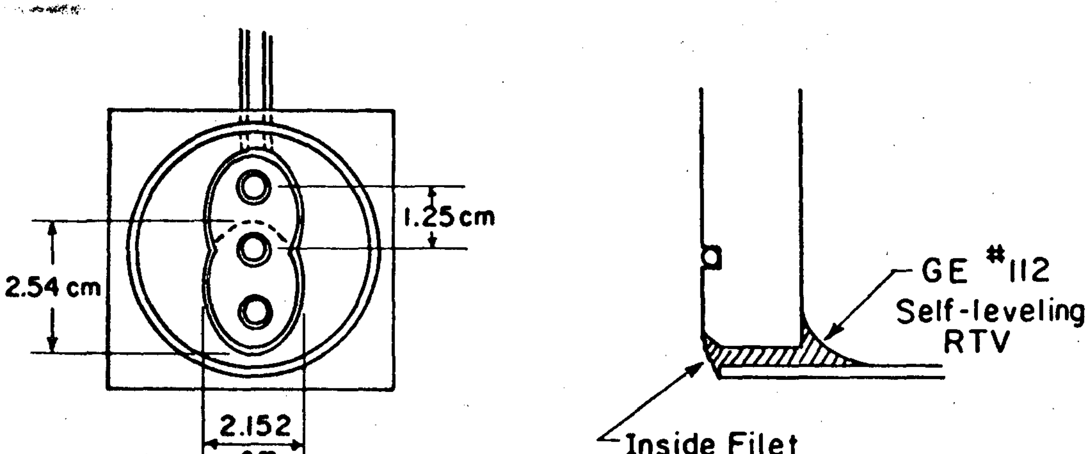


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Fig. 1

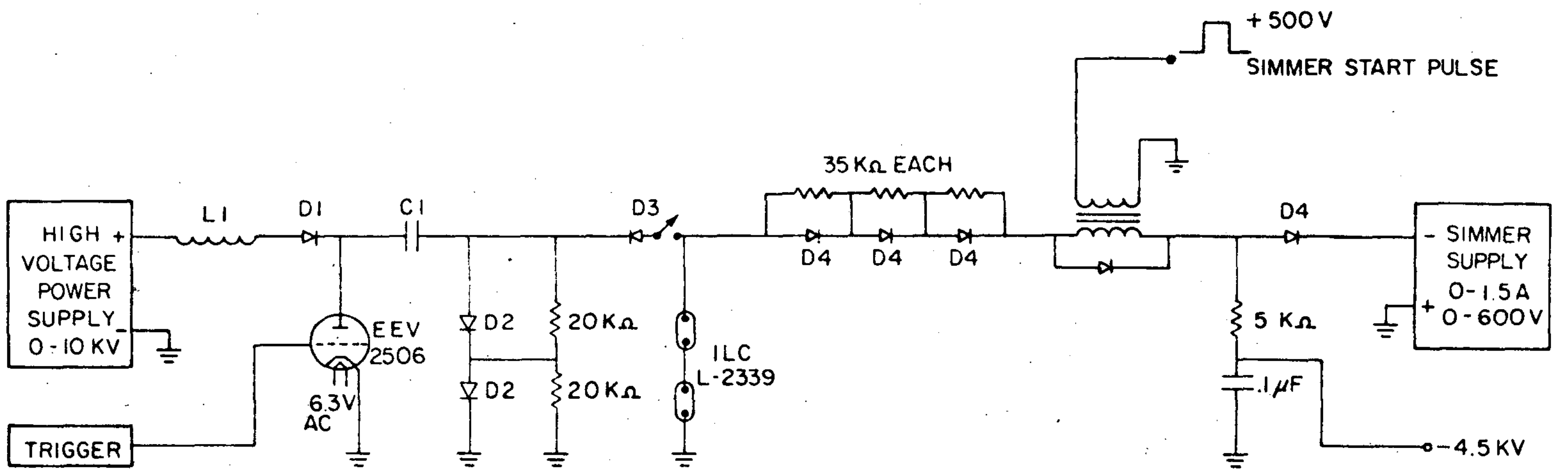

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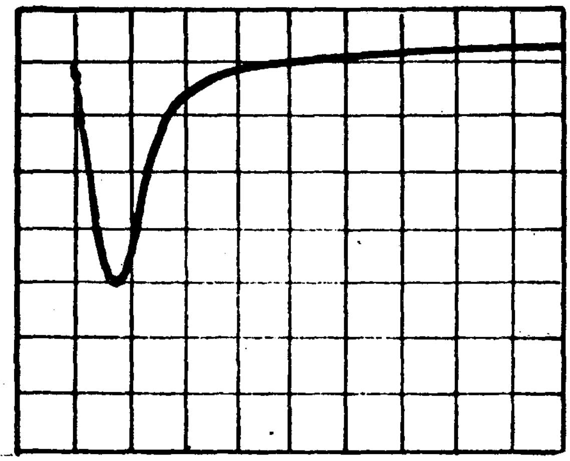
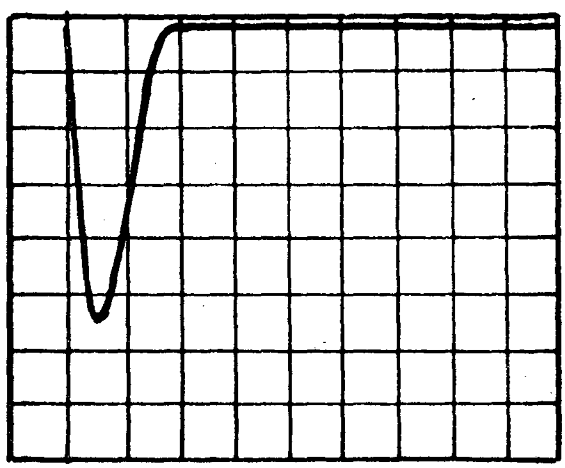
Fig 2



(a)



(b)

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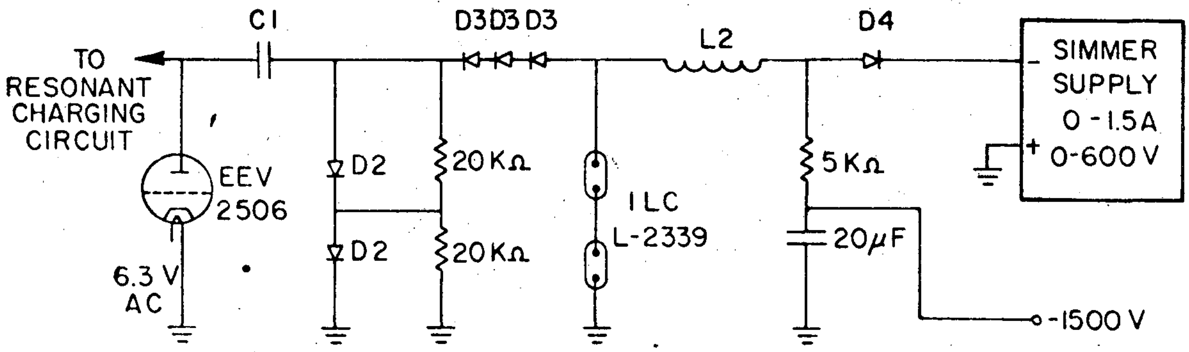
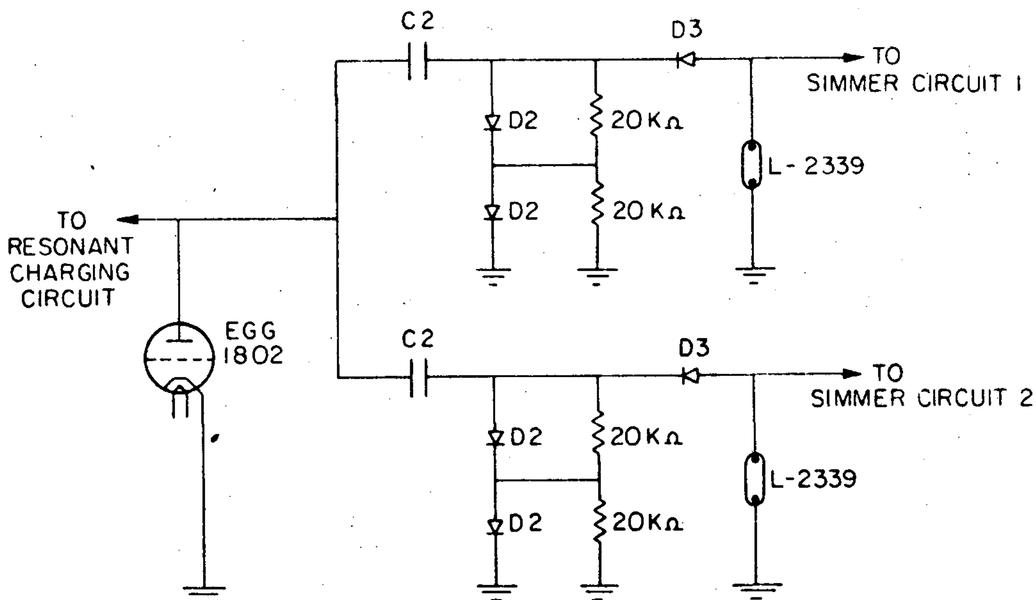
Fig. 3



(a)



(b)

XBL 788-5545

Fig. 4

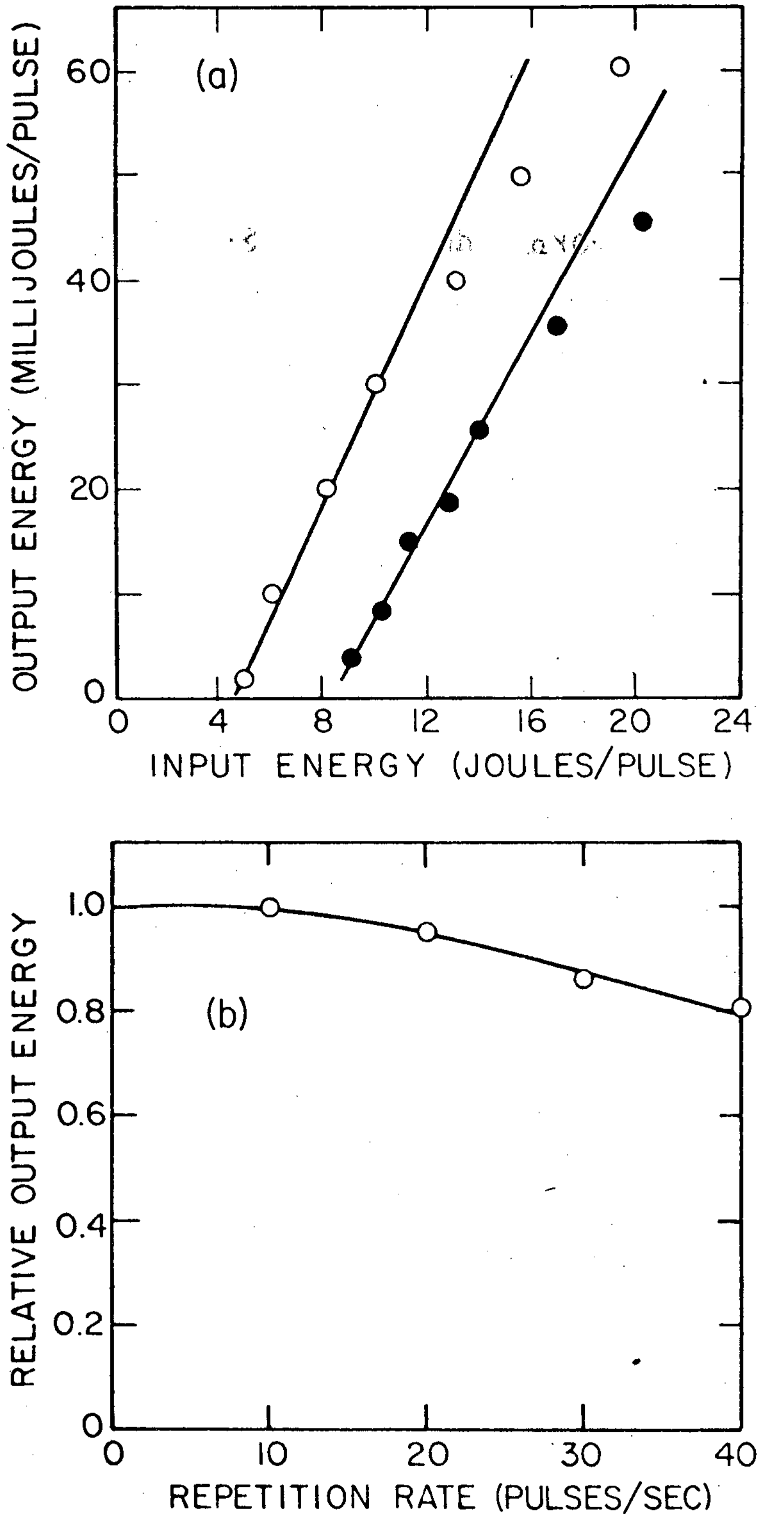


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Fig. 5