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CONSTANT PULSE ENERGY POWER SUPPLY FOR A HIGH REPETITION RATE LASER SYSTEM

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Constant Pulse Energy Power Supply for a High Repetition Rate Laser System

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Abstract

A pulsed power supply system with constant pulse energy has been developed to drive flashlamps in a 0.5-5pps Nd:glass laser system. By using a stable, absolute reference voltage source to set the trigger level, the energy discharged through the flashlamps is kept constant despite pulsing frequency change, power line fluctuation, and minimum dc power supply regulation. The concept can be expanded or adapted to operate other similar systems.

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Introduction

Recent research and development[1] in high repetition rate flashlamp-pumped solid-state lasers have created a need for stable, pulsed power supply. Conventionally, the power system consists of a dc power supply which energizes the capacitor bank in the pulse-forming network. The electrical energy stored in the capacitor bank is then discharged through the flashlamps, generating a light pulse to excite the laser. For low repetition rate systems, one pulse per second (pps) or below, a slow resistive charging scheme is adequate. However, as the repetition rate goes up to 2pps or beyond, the resistive charging technique, which has a maximum possible efficiency of 50% becomes inefficient and cumbersome. It is at this point that a resonant charging scheme becomes desirable.

The resonant charging technique definitely improves[2] the efficiency of the charging system. With careful design, such system can have an efficiency as high as 95%. However, pulses with a constant energy remains a problem. The dc output voltage of conventionally regulated power supply has ripple at line frequency or its harmonic. The ripple in the dc output causes fluctuation in the discharge voltage, hence the discharge energy, from pulse to pulse. In an ideal case where the final charged voltage is twice the dc output voltage, a small ripple in the dc output will produce a fluctuation in the energy stored in the discharge capacitor four times larger. This becomes worse as the consumed power approaches the capacity of the dc power supply. The fluctuation in laser pumping is sometimes unacceptable, particularly for the case of passively mode-locked[3] lasers. To have reliable and reproducible mode-locked operation a set of stringent operating conditions[1,4] must be satisfied.

It is the purpose of this paper to present a novel solution to these problems with a simple but effective control circuit which sets a constant amount of energy per pulse to be discharged, regardless of operating repetition rate and marginal dc power supply regulation.

System Design

Ripple in the output of the dc power supply can be greatly reduced by designing a power supply with higher capacity and better regulation. But this approach is expensive and rather inflexible for developmental lasers. Another approach[5] to eliminate the fluctuation is to synchronously discharge the stored energy in the capacitor bank at line frequency or its (sub)harmonic. This requires a complicated control circuitry and operating frequencies are restricted to discrete ones.

Another approach is to discharge the stored energy at a fixed capacitor voltage. The capacitor bank is charged to a voltage higher than a preset level and is then allowed to decay to the level. The remaining stored energy is then discharged at this instant, thus generating an electrical pulse with a fixed amount energy, independent of the peak voltage on the capacitor bank. It is possible to initiate the discharging during the voltage rise at the preset level. In the present system, however, silicon-controlled rectifiers are used as a switching element in the charging circuit and they may not have turned off during the rise period. If this is the case, the entire energy in the main storage capacitor will be dumped into flashlamps. This may permanently damage components in the power supply system if the current pulse exceeds the current rating of the components.

Figure 1 illustrates the essential features of the pulsed power supply. The output of the dc power supply is controlled by a variac which can adjust the dc output voltage from zero to 2500V. A zero-start circuit is designed into the system to protect the rectifier bridge in the power supply from being damaged by surge current in case the main power supply switch is activated with the variac set at a high output level. The main energy storage capacitor is C_1.

The resonant charging circuit is formed by the inductor L_1 and the discharge capacitor C_2 with the silicon-controlled rectifiers SCR_1-SCR_7 as the switching element. The seven SCRs, being connected in series, have a total breakdown voltage rating of 7000V.

At initiation of a start pulse (Figure 2a) by the momentary switch, the single-shot multivibrator M_4 generates a pulse (Figure 2b) which triggers SCR_8, thus discharging the energy stored in the capacitor C_3 into the primary winding of the transformer T_1. T_1 has an Arnold Engineering type AL98 core, and the turn ratio of the primary winding to the secondary is 200:2. Each of the seven secondary windings of T_1 provides a driving pulse for each SCR. At the end of a time period determined by $\pi\sqrt{(L_1C_2)}$, the voltage across C_2 ideally would have charged up to twice that across C_1 (Figure 2c). However, this usually falls short because of the limited energy stored in C_1. At this instant the voltage across C_2 starts to decay with a time constant given by $\tau = RC_2$, where R is the total resistance of the bleed-down resistors R_{11}-R_{14}, connected in parallel to the flashlamps. This change in voltage across C_2 is monitored by a resistive voltage divider.

The attenuated voltage across the capacitor bank and a precision reference voltage are inputs to the voltage comparator M_1. During the rise and fall of the voltage across C_2, the comparator changes its output state once when the voltage across C_2 exceeds a preset level and another time when the capacitor voltage falls below the same level (Figure 2d). The single-shot multivibrators M_2 and M_3 are both triggered by the trailing edge of the output of the comparator. M_2 provides a trigger pulse (Figure 2e) for SCR_9 and SCR_{10} which, in turn, trigger the flashlamps by means of the transformer T_2. Series-injection method is used to turn-on the flashlamps which are connected in series. The waveform of the discharged pulse is determined by the pulse-forming network consisted of the discharge capacitor C_2 and the secondary winding of T_2. Since the arc resistance of the flashlamps is of few ohms, much smaller than the bleed-down resistance, almost all discharged energy is consumed by the flashlamps. The voltage level V_d at which M_2 is triggered sets the amount of the electrical energy, $C_2V_d^2/2$, to be discharged through the flashlamps. Since V_d is set with a stable, absolute reference voltage, the energy available remains constant each and every pulse as long as the peak voltage across C_2 exceeds V_d.

The dc reference voltage is set by R_{30} which is able to adjust the trigger level continuously from zero to 5V. Since the divider has an attenuation factor of 1000, the 0-5V adjustment is equivalent to a range of 0-5000V for V_d. As the reference voltage is derived from a precision voltage with a voltage variation less than 5mV, the fluctuation in the discharge voltage due to reference variation is negligible. Care is taken to shield the control circuit from electrical noise which will degrade the circuit performance.

In the meantime, the single-shot multivibrator M_3, being triggered, provides a delay gate (Figure 2f), whose duration is determined by the resistors R_{43} and R_{44} and the capacitor C_{18}. At the end of the delay gate, M_4 is triggered again (Figure 2b), generating a trigger pulse for SCR_8, thus the cycle starts all over again. The delay gate determines the operating frequency of the pulsed power supply system. In the present case, the resistor R_{43} is used to set the pulse repetition rate from 0.5pps to 5pps.

Discussion

The system has been used to excite a high repetition rate Nd:glass laser capable of operating at 5pps. The laser is described elsewhere[1]. Figure 3 shows an oscillogram of five light pulses of flashlamps, as detected by a photodiode, superimposed on each other. The output variation is insignificant although a fluctuation in the peak voltage on the discharge capacitor of as much as 10% is observed at 5pps.

The choice of triggering the flashlamps during the voltage decaying period assures a constant energy to be discharged, independent of the dc power supply variation and the system pulsing frequency. The fluctuation in the discharge energy from pulse to pulse, introduced by the reference voltage fluctuation and the trigger jitter in the voltage comparator, is about 10^{-3}. This can be reduced by using a smaller attenuation factor of the voltage divider for sensing the capacitor voltage, and components of better specifications. A fluctuation also results from the jitter in triggering the flashlamps which is about 30 μsec. As this time is much smaller than the bleeddown decay constant of 150 msec, the energy fluctuation due to this flashlamp jitter is less than

5×10^{-4}. There is a jitter in operating frequencies due to variation in the dc power supply output. However, frequency jitter, which is at most 10% in the present case, does not affect laser operation as the laser cavity configuration is in a thermal steady state at a repetition rate beyond 0.5pps.

In conclusion, the control circuit presented in this paper can be designed to operate at higher power levels as well as higher operating frequencies. The concept of setting the trigger level with a stable absolute reference voltage source is simple yet effective. The advantage of constant energy pulses certainly outweighs the small power dissipated by the bleeddown resistors before discharge is initiated.

Acknowledgments

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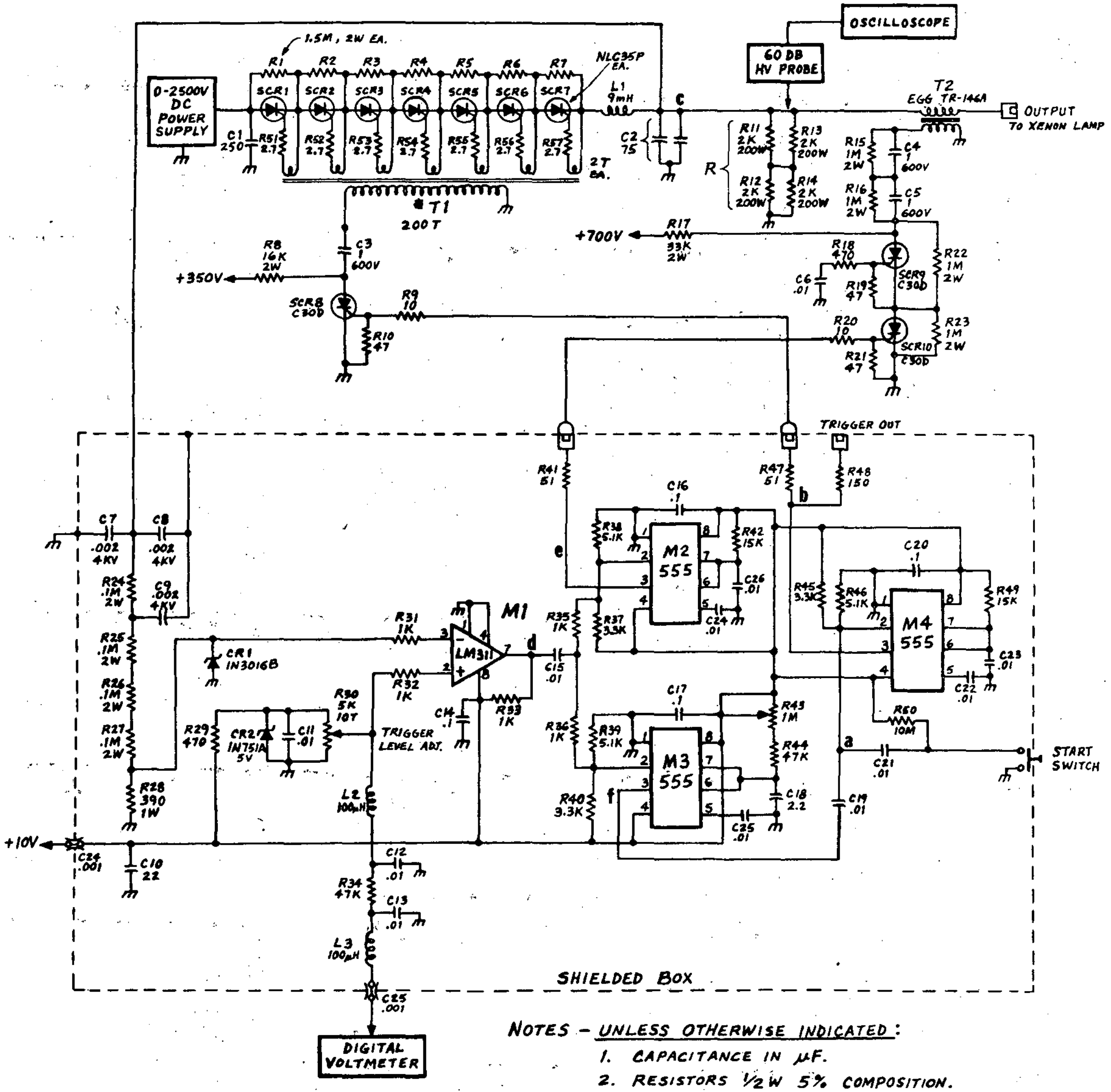
4. D. B. Hopkins (private communication).

Figure Captions

Figure 1	Schematic diagram of the constant energy pulse power supply.
Figure 2	Waveforms showing sequence of operation of the system.
Figure 3	Light output pulses of flashlamps.

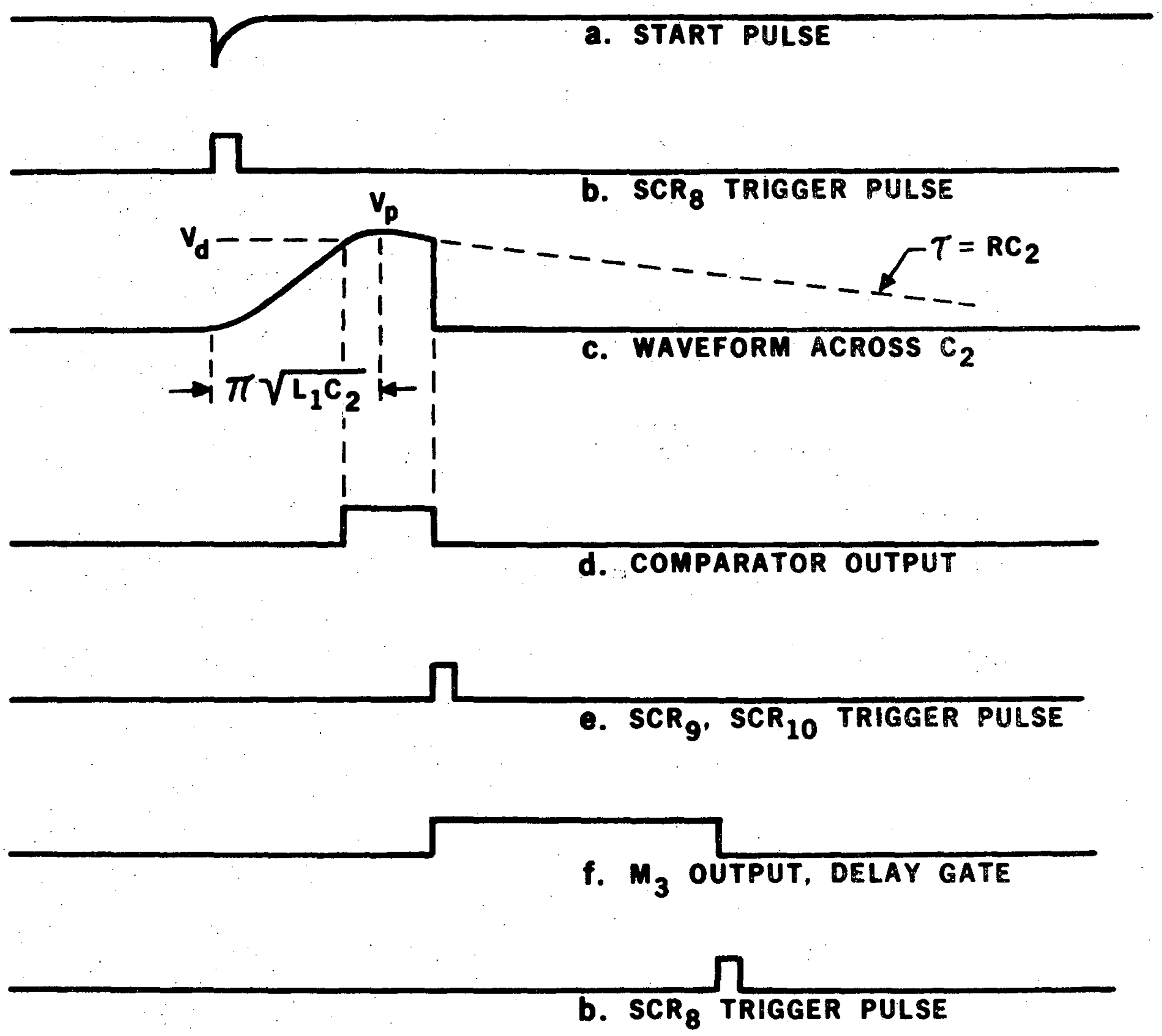


NOTES - UNLESS OTHERWISE INDICATED:

1. CAPACITANCE IN μF.
2. RESISTORS ½W 5% COMPOSITION.
* 3. ARNOLD ENGINEERING AL98 CORE.

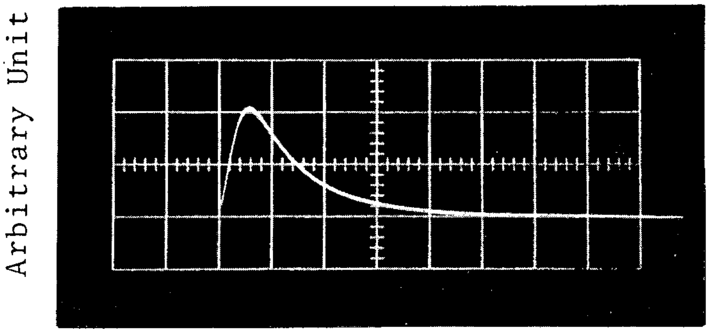
FIG. I

XBL 753-450



XBL 753-451

FIG. 2



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100 usec/Div.

Fig. 3

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