ACKNOWLEDGMENT

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3.B An Ultra-Stable Nd:YAG-Based Laser Source

A stable source is essential for the careful study of any nonlinear process. Current systems attain ±5% energy stability from shot to shot.[1,2] A newly developed system operates much more consistently. Laser oscillator pulses from this system are stable to ±0.8%, and amplified pulses (up to 100 mJ) are stable to ±2%. The oscillator can operate at pulse rates up to 500 Hz and the amplifier up to 10 Hz.

Elements of the System

The system configuration is shown in Fig. 19.22. The oscillator is a continuously pumped Nd:YAG laser which is mode-locked and repetitively Q-switched at any rate between 0 and 500 Hz. The peak pulse in the 20- to 25-pulse FWHM output train has an energy of 120 μJ. A recently developed Pockels cell driver, capable of operating at repetition rates above 500 Hz, selects the peak pulse from

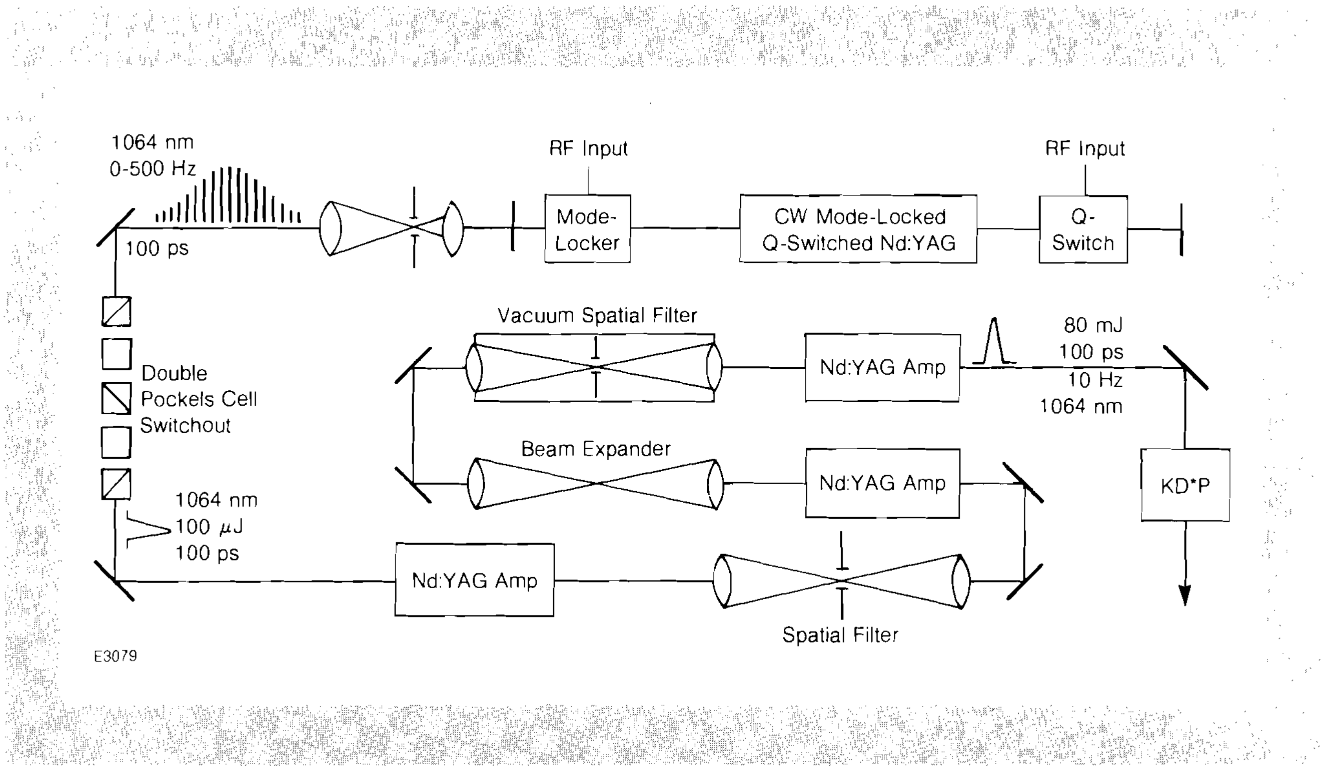

Fig. 19.22
System layout for the improved laser oscillator and amplifier.

the pulse train. This pulse propagates through three single-pass Nd:YAG amplifiers which are separated by spatial filters to maintain the beam quality. Output energies of as much as 100 mJ have been obtained at amplifier repetition rates up to 10 Hz. A doubling crystal may be inserted in the output beam as shown.

With continuous pumping, the oscillator operates at a low prelase level prior to the Q-switch. During the prelase period, transient relaxation oscillations decay (see Fig. 19.23), and the laser emission becomes fully mode-locked prior to Q-switching. This ensures that a consistent-amplitude, fully mode-locked pulse is present in the cavity when the laser is Q-switched. Thus, the prelase stabilizes the output pulse energy, duration, and build-up time. Output stability is further improved when the acousto-optic mode-locker and Q-switch are driven by the same rf source.

Resonant frequencies of the acousto-optic mode-locker vary significantly with temperature. We stabilize this device by regulating the input rf power and by cooling the acousto-optic crystals with a water bath regulated to 0.1°C.

Since the Q-switch is gated on a zero crossing of the RF, driving both the mode-locker and Q-switch from the same source defines the position of the pulse in the cavity when the Q-switch is triggered. In order to avoid undesirable interaction with the mode-locker, the Q-switch is placed in the optical center of the cavity.

The mode-locked laser is extremely sensitive to variations in the cavity length. To minimize thermally induced changes in the cavity

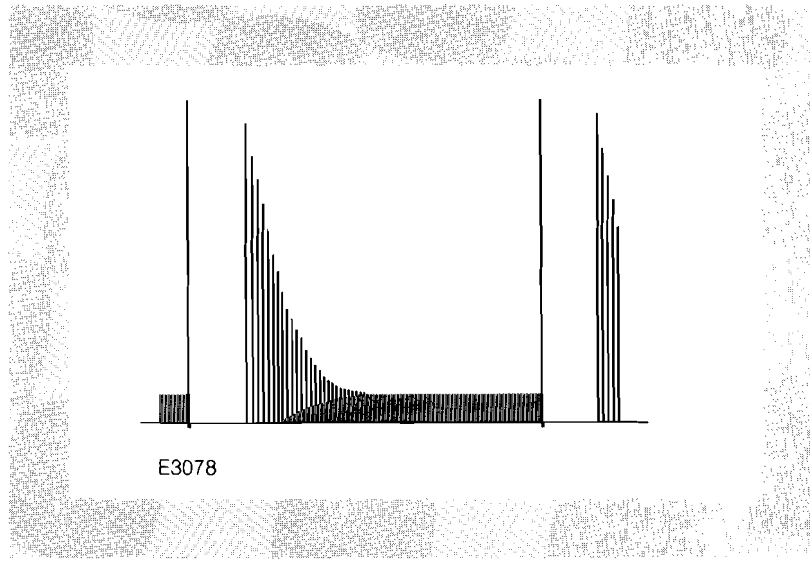

Fig. 19.23
Detail of the relaxation oscillation decay and prelase for the laser oscillator.

length, the end mirrors are mounted on a bar of Invar. The dc current to the arc lamp is also stabilized by an additional filtering capacitor and inductor to limit current fluctuations to less than 0.1%.

With these modifications this Nd:YAG oscillator produces a train of laser pulses, 25 pulses wide, with a peak pulse energy of 120 μJ at *any* repetition rate up to 500 Hz. The mode-locked pulse duration is measured at 100 ps.

The Pockels-cell switchout is driven by a new circuit developed to solve the short lifetime, limited repetition rate, and jitter problems of the krytron-driven switchout. The new design[3] incorporates a "hard" tube (microwave vacuum triode) whose grid is driven by a one- to two-transistor avalanche stack. The Pockels cell (PC) is built into the circuit package and is treated as a capacitor by the circuit. The circuit diagram is shown in Fig. 19.24.

The PC is charged to high voltage through a storage capacitor. The shunt resistance across the PC is adjusted to provide a 1- to 10-μs cell-discharge time constant. The PC capacitance is much less than the storage capacitance so the cell charges to full voltage when the tube conducts. Between firings, however, the PC potential returns to zero while the storage capacitor recharges.

Operation in this configuation produces a voltage function with a rise time of < 5 ns and a fall time of 1-10 μs. This function can be used either as a step-transmission function (if the final voltage is the half-wave voltage, $V_{\lambda/2}$) or as a switchout (if the final full-wave voltage is V_{λ} and the pulse is timed to correspond with the voltage passing through $V_{\lambda/2}$). When used as a switchout for a Q-switched laser, the second crossing of $V_{\lambda/2}$ (during the 1- to 10-μs decay) will occur after lasing has stopped.

In an alternate configuration, an avalanche transistor stack is connected across the PC (denoted by dashed lines in Fig. 19.24). The breakdown of this stack is adjusted so that it occurs when the

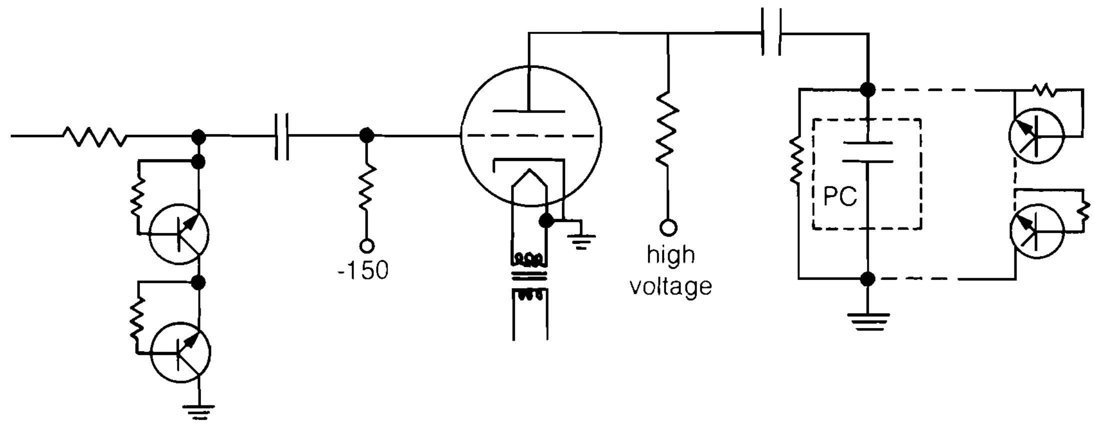

Fig. 19.24
Electrical schematic of the recently developed Pockels cell driver.

PC reaches $V_{\lambda/2}$. This option produces a PC voltage with a 5-ns rise, a ~ 5-ns fall, and a peak value of $V_{\lambda/2}$. This fast signal provides a 1- to 2-ns transmission window for pulse selection.

Timing for the PC trigger is accomplished by counting cycles of the mode-locker rf. Small adjustments are made by phase shifting the rf to the mode-locker. The total delay inserted is approximately 3 μs. The Q-switched buildup time is sufficiently stable to select the peak pulse consistently.

The shot-to-shot jitter is $<$ 100 ps. There is also no apparent drift over weeks of operation. The tube is guaranteed to last for one year. At present over $2 \cdot 10^7$ shots have been accumulated with no apparent degradation. This performance is to be compared with that of a krytron switchout driver which has shot-to-shot jitter of $>$ 1 ns, a lifetime drift of $>$ 10 ns, and a tube lifetime of 10^7 shots. At a repetition rate of 500 Hz this allows approximately eight hours of operation. The new circuit design shows no change in performance as the repetition rate is increased. Rates as high as 1 kHz have been obtained, limited by only the power supplies and heat dissipation in the charging resistors.

The amplifier chain consists of three in-line amplifiers. The single pass gain of each can be as high as 30. Rod diameters in the first two heads are 7 mm. They are separated by an air spatial filter which maintains the beam quality and adjusts the beam size. Following the second amplifier is a focusing beam expander and a vacuum spatial filter. The output of the third (9-mm diam) amplifier is a 100-ps pulse of up to 100-mJ energy.

The IR pulse from the amplifier chain is frequency-doubled in an angle-tuned KD*P crystal. An overall energy conversion efficiency of 60% is routinely obtained. Both the green and the IR are used to drive experiments and detection equipment.

System-Operating Characteristics

The important characteristic of this system is the remarkable amplitude stability which results from combining the cw mode-locked, Q-switched Nd:YAG with the newly developed switchout. Figure 19.25 is a histogram of the normalized oscillator pulse energy for 1000 shots at 20 Hz. The average value is 100 with a full-width half-maximum of 1.6 which indicates a stability of ± 0.8%.

The process of amplification does add some fluctuation as illustrated in Fig. 19.26, a histogram of the amplified pulse energy. In the same manner the fluctuation is calculated as ± 2%.

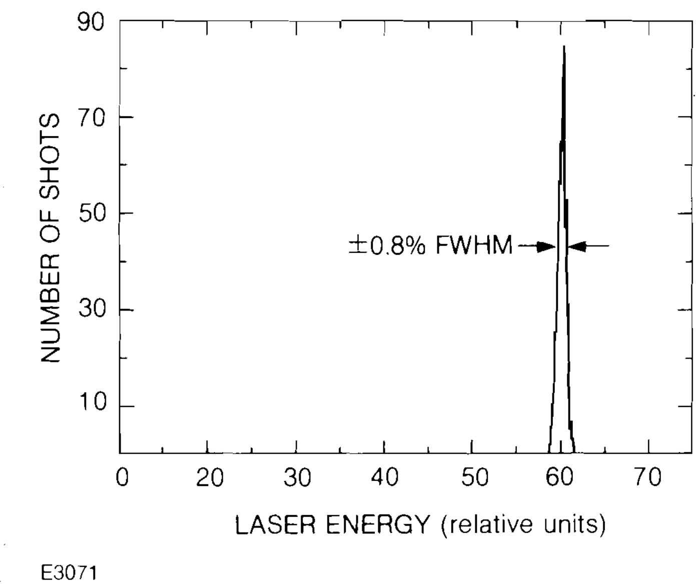

Fig. 19.25
Energy stability histogram for the laser oscillator and pulse selector.

Summary

The new laser source is exceptionally stable and operates at high repetition rates. Stability is attained because we have incorporated close control of the parameters that affect it into the design of the system. The new, hard-tube Pockels-cell driver enables high-repetition-rate operation.

This new source substantially increases our capability to measure rapid transient phenomena. The precision of statistical sampling techniques is improved by the stability of the source energy. Moreover, the high pulse energy extends the dynamic measurement range to lower levels.

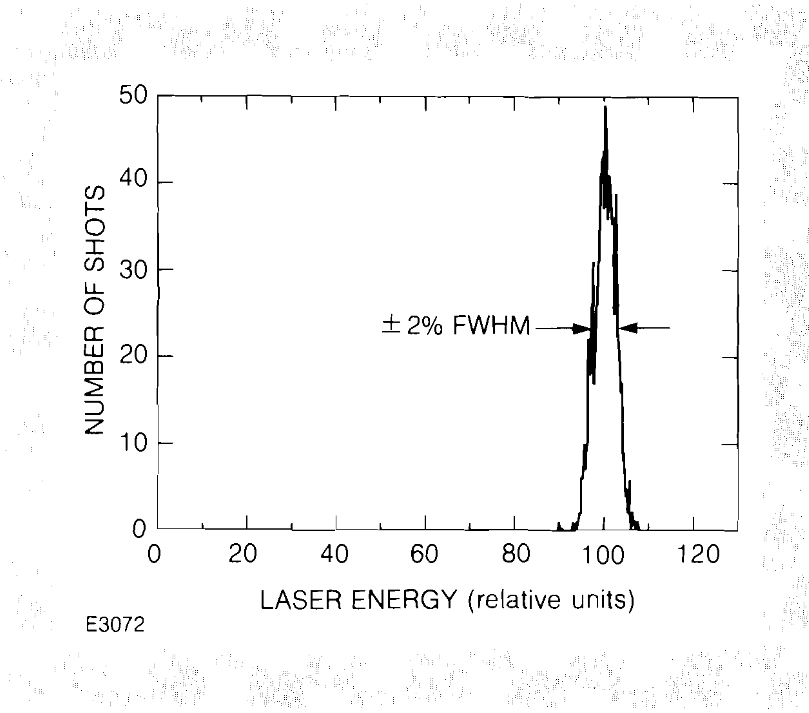

Fig. 19.26
Energy stability histogram for the amplified 1.06-μ laser pulse.

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