Computercontrolled highspeed peak detector for use with pulsed lasers

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Computer-controlled high-speed peak detector for use with pulsed lasers

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A simple, computer-controlled high-speed peak detector for monitoring relative energies in experiments that involve pulsed lasers, is described. In many experiments the laser pulse energy is monitored by feeding the output from a photomultiplier to the 1 MΩ input of an oscilloscope having a bandwidth of about 100 MHz. The computer-controlled peak detector described in this paper can effectively replace the oscilloscope in such cases. There is, further, an additional advantage that the data can be processed shot by shot. High speed and long hold time are achieved by using two peak detectors in tandem. The first peak detector is capable of tracking fast pulses, but has a low hold time. The second peak detector is slower than the first but has a long hold time. The peak value is held for several minutes without appreciable decay, so that several channels can also be monitored one by one manually with an ordinary volt meter. Its versatility in measuring shot-to-shot energy variation of laser pulses, and in real-time pulse selection are demonstrated. Saturation characteristics of a nitrogen laser pumped dye laser has also been studied with two such peak detectors operated simultaneously. © *1995 American Institute of Physics.*

I. INTRODUCTION

In many experiments that use pulsed lasers the quantity that is often measured is the energy of the laser pulse. Examples of such experiments include gain measurements in dye lasers,[1–3] energy transmission through saturable absorbers,[4] etc. The simplest way to measure the energy in a laser pulse is to use a fast photodiode or a photomultiplier (PMT) to convert the light pulse to an electrical pulse and feed this electrical pulse to the 1 MΩ input of an oscilloscope of, say, 100 MHz bandwidth. The 1 MΩ input resistance, along with its usual parallel capacitance of about 30 pF, integrates the pulse. The amplitude of the integrated pulse is proportional to energy in the laser pulse. In cases where only the relative values of the energy are of importance, this arrangement can serve as a cheap and reliable relative energy meter. However, if one wants to look at the pulse-to-pulse variation in the energy or if the pulse repetition rate of the laser is very low, then it is not convenient to use an ordinary analog oscilloscope. Since only the peak value of the observed signal is of interest, a fast peak detector is sufficient to measure the energy on a relative scale. A peak detector is a special kind of sample hold circuit. The peak detector is required to have fast rise time to follow and capture the integrated pulse. After capturing the peak its value must be read and then the peak detector has to be reset. Generally, in many laser experiments, several optical detectors have to be monitored simultaneously. Thus the peak detector must hold the captured values long enough for the operator to read them one by one. These operations, if they have to be carried out manually, are slow and tedious and hence manageable only at very low repetition rates. But even at repetition rates of a few pulses per second, manual operation becomes impractical.

A few papers presenting the design and applications of peak detectors have appeared in the past.[5–7] In Ref. 5 a peak height measuring system is described to measure the intensity rather than the energy of a single laser pulse. This design uses discrete transistors in its design. A much simpler peak detector built with integrated circuit operational amplifiers is described in Ref. 6. The authors use a 10× amplifier stage in front of their peak detector to measure optical pulse energies as small as 1 nJ but the reset switch is manually operated, thus limiting its application to very low repetition rate lasers. Efficient signal recovery in a laser opto-galvanic spectroscopy (LOG) experiment using a peak detector is described in Ref. 7. A metal-oxide semiconducting field-effect transistor (MOSFET) switch is used in their work but it is not operated under computer control. All these designs use only one stage for peak detection. Thus the active components must have characteristics suited for both high speed as well as long hold time but they are rarely found together with simultaneously satisfactory characteristics of high speed as well as long hold time.

In this paper we describe a simple two-stage peak detector. This design gives simultaneously satisfactory characteristics of very high speed as well as very long hold time. This is achieved by cascading two peak detectors. This peak detector can be operated either manually or under computer control. Because the entire operation can be automated, this two-stage peak detector is useful for looking at the pulse to pulse variation in the energy of a laser operating at pulse repetition rates of more than ten pulses per second. Also this computer-controlled peak detector can be programmed to accept, in real time, only those pulses that fall within certain prespecified upper and lower bounds of voltage which can correspond to specified limits of laser energy.

In Sec. II the conventional peak detector is reviewed and the cascaded arrangement of peak detector is described. In Sec. III design details of the high-speed peak detector circuit are given. Section IV gives details of the computer-controlled operation of the peak detector and Sec. V presents some of the results obtained with this peak detector.

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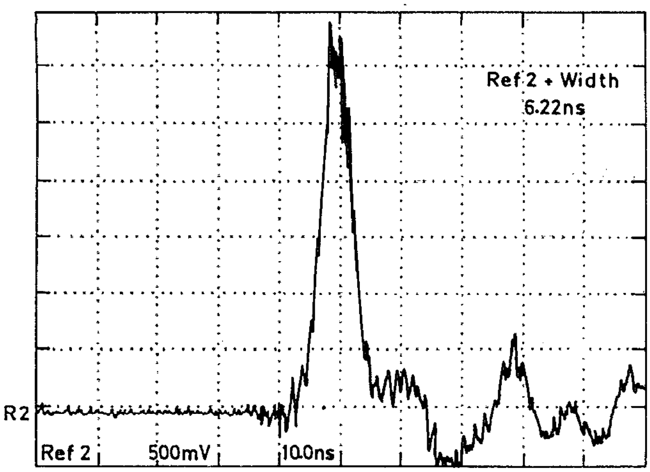
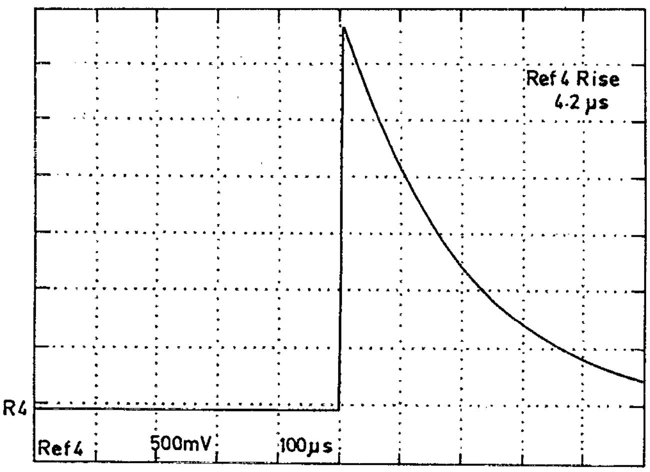


(a)



(b)

FIG. 1. (a) Typical oscilloscope trace of a nitrogen laser pulse obtained with a high-speed photodiode connected to the 50 Ω input of a wide band oscilloscope was used to observe the nitrogen laser pulse. (b) The same nitrogen laser pulse observed with the photodiode connected to the 1 MΩ input of the oscilloscope. The peak value of the signal shown in (b) is proportional to the energy in the laser pulse.

II. THE PEAK DETECTOR

To illustrate the performance requirement of any peak detector for monitoring the energy output of short pulse lasers, a nitrogen laser pulse detected with a high-speed photodiode (Motorola, MRD 510) and a 500 MHz digital storage oscilloscope (TDS 520A, Tektronics) are shown in Fig. 1. Connecting the photodiode to the 50 Ω input (or using a 50 Ω terminator at the input) of the oscilloscope and adjusting the sweep speed, the actual shape of the nitrogen laser pulse (pulse width 6 ns) is obtained, a typical signal being shown in Fig. 1(a). When the photodiode is connected to the 1 MΩ input of the oscilloscope, the same signal appears as shown in Fig. 1(b). In this case the rise time of the pulse was measured to be 4.2 ns. The peak value of this integrated trace is proportional to the energy in the laser pulse. Any peak detector meant for capturing this peak value must be fast enough to follow the rising edge (rise time ~4 ns) of the pulse shown in Fig. 1(b).

A conventional peak detector built with two operational amplifiers is shown in Fig. 2. The output of the opamp A1 tracks the applied signal and charges the capacitor C1 through the diode D1 as long as the input is increasing. The output of the second opamp A2, which follows the voltage across the capacitor C1 is applied to the inverting terminal of the first opamp. After the peak value is reached, the input to A1 starts going down and the diode D1 becomes reverse-biased. Without the diode D2 the output of A1 will go to a negative saturation voltage. Operational amplifiers take considerable time to recover from such saturation. In addition, if another pulse of higher amplitude follows, then the output of A1 has to rise all the way from the negative saturation value to reach the amplitude of the present pulse. This will result in the speed of the peak detector being greatly reduced.

The second diode D2 prevents the opamp from going to negative saturation values and clamps the output to one diode drop (0.7 V) below the zero of the supply. This improves the speed of the peak detector considerably. To prevent the charge stored in C1 from leaking away three things must be done:

(1) Diodes with very low reverse leakage current should be used. Junction field-effect transistor (JFET) can be used as low leakage diodes, as described later.

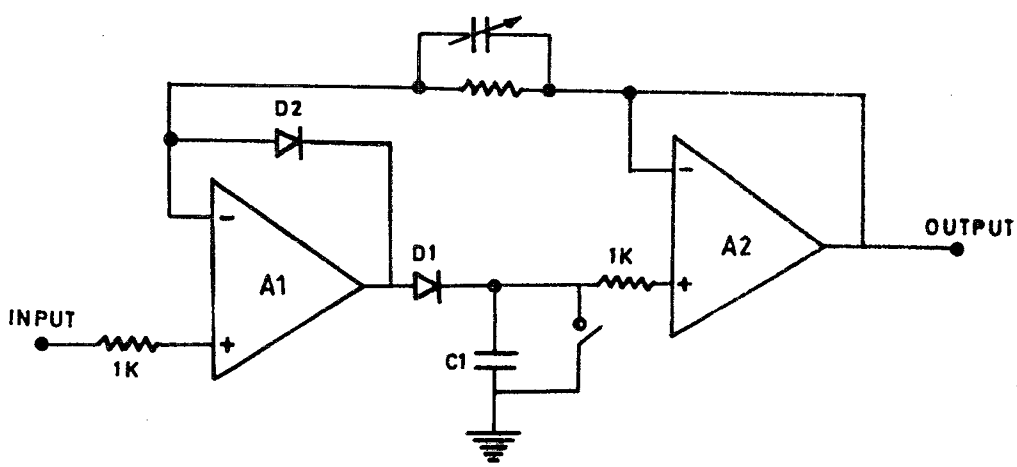


FIG. 2. Schematic diagram of a conventional peak detector.

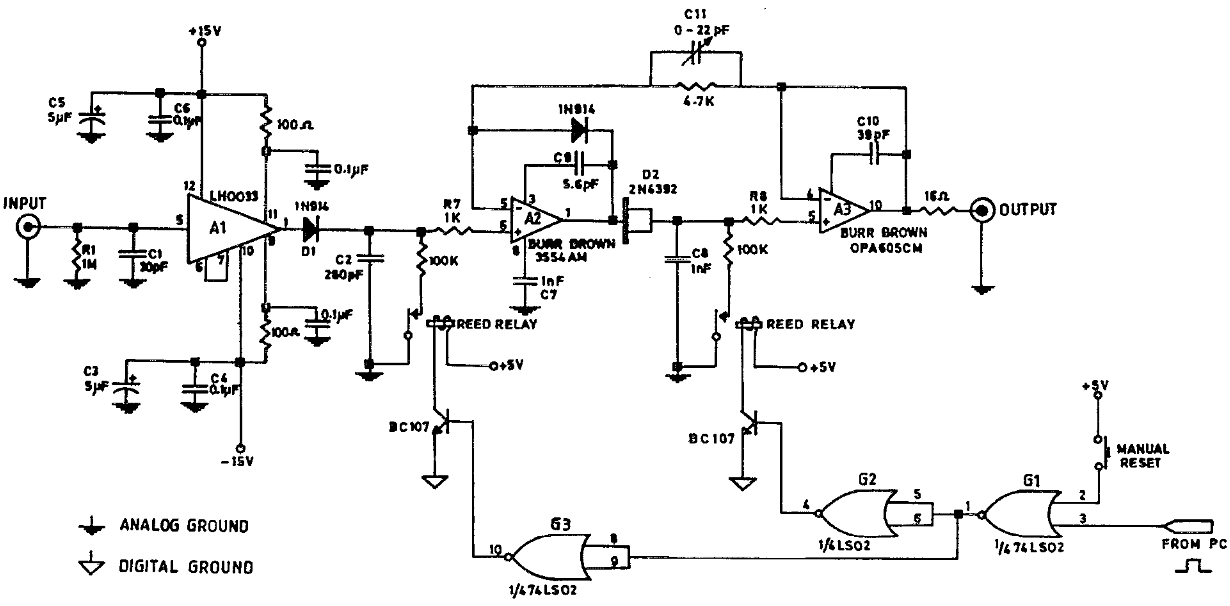


FIG. 3. Circuit diagram of the two stage peak detector.

(2) Operational amplifiers with very low input bias current should be chosen for buffer amplifier A2 (FET input opamps have been used in our design).
(3) Low leakage capacitors like Teflon or glass capacitors should be used for storage.

The rate at which the output of an opamp can change is given by its slew rate. Since A1 has as its load a large capacitor, the output current capability of this opamp should also be adequately high. When the load capacitance is high many operational amplifiers tend to become unstable[8] and need to be carefully compensated.

The design of a conventional peak detector presents a practical problem when transported to high-speed regimes. The rise time of the voltage across C1 is not determined by the time constant of the ON resistance of the diode D1 times C1 but is dependent only on the current capability of the opamp A1.[9] The output slew rate is given by $I_{max}/C1$ (V/s), as long as this value is not larger than the specified maximum slew rate of A1. Therefore, the first operational amplifier A1 should have a high slew rate as well as large output current capability. Also the buffer amplifier A2 should have as low a leakage current as possible but at the same time have low transit time and high slew rate. In practice it is either difficult to get operational amplifiers with such specialized characteristics or they are expensive.

One simple technique to overcome the above-mentioned difficulties is to cascade two peak detectors. In the circuit presented in this paper, the first peak detector uses an opamp which has a very high slew rate (1000 V/s). To preserve its slew rate, a small capacitor (280 pF) is used as its load. As a consequence, this peak detector can track very fast pulses and detect their peak but can hold the peak voltage only for a short duration. The second peak detector is slower than the first, but fast enough to reach the peak before the first peak detector's output decays appreciably. The second peak detector uses a large storage capacitor (1 nF) and a high input impedance buffer stage so that the peak value detected is retained for several minutes. After reading the stored peak value the capacitors can be discharged and the peak detector is ready for the next input.

III. CIRCUIT DESCRIPTION

The circuit diagram of the two-stage peak detector is shown in Fig. 3. The circuit shown is that of a positive peak detector. When the circuit is used with a PMT, which produces negative pulses, the circuit of Fig. 3 is converted for negative peak detection by reversing the polarities of all the diodes.

The input resistance R1 and capacitance C1 were chosen to simulate the input of an oscilloscope (100 MHz, analog) which we had been using in our previous experiments. The value of C1 (26 pF) along with the input capacitance of A1 (~4 pF) is roughly equal to the input capacitance of such an oscilloscope. Diode D1 prevents the capacitor from discharging through the output terminal of A1. National Semiconductor LH0033 used here as A1, is a very high-speed, high-current buffer amplifier. Its slew rate is unaffected by capacitive loads up to 280 pF. Thus a ceramic capacitor of this value is used as C2. This capacitor, because of its leakage resistance and also because of leakage through D1, cannot hold charge for more than a second. It can be shown that the voltage across the capacitor C2 decreases by a negligibly small amount in the first few microseconds that are required for the second peak detector to catch up with the first. The second stage is a conventional peak detector which uses two high-speed FET input operational amplifiers. Burr Brown 3554 was chosen as the input stage for this peak detector (A2) because of its high-current capability (100 mA) and high slew rate. Also, it is stable with capacitive loads exceeding 1 nF. This opamp charges a 1 nF storage capacitor C8. Since glass or Teflon capacitors (ultralow leakage capacitors) were not available for us, we used a polystyrene capacitors.

Since the output is digitized within a few tens of milliseconds, the error produced due to leakage is negligible. Diode D2 is actually a junction field-effect transistor (2N4392, siliconix). This JFET is converted to a low leakage diode by tying its source and the drain leads together and using them as the cathode. The gate lead of the JFET is used as the anode. Capacitor C7 was used as per manufacturer's direction for capacitive load applications. C9 and C10 are the compensation capacitors, chosen carefully after many trials to give minimum overshoot. These values are strongly dependent on the circuit layout. Resistors R7 and R9 protect the opamps from damage caused by current surges that occur while turning on the power to the circuit. While charging, the storage capacitors draw a lot of current from the power supply. This can lead to a voltage drop in the wiring and may disturb the normal operation of the peak detector. To overcome this a 5 μFd tantalum capacitor was connected between each of the supply leads and the ground. These capacitors act like local current sources and supply the necessary current when the opamps need it. Similarly low inductance ceramic capacitors (0.1 μFd) were used to bypass the transients that may appear in the supply lines. These capacitors should be placed as close to their respective opamps as possible. In our circuit they were placed within 15 mm of each opamp. Though these capacitors were employed for all three opamps, they are shown (C3, C4, C5, and C6) only for A1 in Fig. 3. The first time the peak detector is turned on, the output may latch up to one of the supply rails. The trimmer capacitor C11 in the feedback loop of the second peak detector had to be adjusted to prevent the output from getting into this latch up condition. We found that once this initial setting is done the peak detector never latches up again.

Typical signals at the input and output of the two-stage peak detector are shown in Fig. 4. The rise time of the signal at the peak detector is about 1 μs. By using smaller impedance for termination instead of 1 MΩ and 30 pF, this same peak detector could be used to detect the peak intensity[5] rather than the energy of the laser pulse. This is because the buffer amplifier A1 used in the first peak detector has adequate current capability to track the fast signals. But in this case the optical detector used must give signals of sufficient amplitude. In the present design the output of the peak detector is offset to one diode drop (0.7 V) above the ground and the peak value is 1.4 V less than the peak value of the input signal. Thus the amplitude of the signal at input of the peak detector should be at least 0.7 V. To detect weak signals a fast amplifier[6] may be used in front of the peak detector.

The storage capacitors C2 and C8 are both discharged by energizing the normally open relays RLY1 and RLY2. These are small PCB mountable relays (PLA Relays, India) that can be energized with a 5 V supply and draw less than 20 mA. These relays are connected to the logic gates as shown in Fig. 3 so that they can be operated by TTL signals from the PC. The NOR gate G3 also allows manual reset of the peak detector. The use of mechanical relays enormously simplifies the circuit design. Our choice of mechanical relays instead of solid-state switches was based on the following:

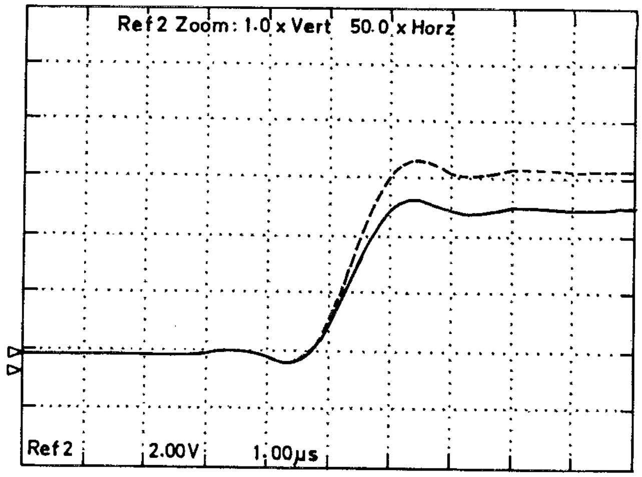


FIG. 4. Typical signals at the input (dotted line) and at the output (solid line) of the cascaded peak detector.

(1) The maximum repetition rate of the laser used in our experiments is 10 pps. Thus between each pulse there is 100 ms. This is greater than the time needed for the relay contacts to close and open which is typically a few ms.
(2) The capacitance between the contacts is much smaller than that obtained in solid state switches. This is very important[8] when the signal contains high-frequency components, as in the present case.
(3) While the lifetime of the mechanical relay may not be as long as that of solid-state switch, it is compensated for in terms of the simplicity and lower cost. The relays used by us have worked for more than 10^5 shots without failure in our circuits. Also since these relays are available in dual inline packages (DIP) similar to that for ICs, they can be plugged into appropriate sockets and so it is very easy to replace them when there is a failure.

The storage capacitors are discharged through the 100 K resistors with their respective time constants. The larger of the two time constants, namely that for the second peak detector is only 0.1 ms. The 100 K resistor is used to limit the current and thus prevent the contacts from fusing together during the discharge.

The ICs used are all high-frequency ICs, the circuit layout was planned to minimize stray capacitance. The leads of all the components were kept very short to reduce inductance effects. In the double-sided printed circuit board designed by us, copper on the component side was left unetched to form the ground plane. The ground for the analog circuit was kept separate from that of the digital circuit and connected together only at a single point near the power supply. This prevents the formation of ground loops that may affect the operation of the digital part of the circuit.

Shielding of the peak detector is absolutely necessary since any noise like the 50 Hz line frequency noise will appear at the output of the peak detector as a dc offset. In our design we have used a simple shield made with 1.5-mm-thick aluminum sheet with holes drilled to allow air to flow over the peak detector circuit boards for cooling purposes. Further, all the electronic circuits and equipment were placed inside a Faraday cage. Because a large current flows through the opamps each time they charge the capacitors, they can get hot and their input bias current will increase. Use of large heat sinks may increase the input capacitance and can slow down the peak detector. Thus instead of using heat sinks we have used forced air cooling for the circuit boards.

IV. OPERATION OF THE PEAK DETECTOR

The output of each peak detector was connected to an analog-to-digital converter (ADC). For this purpose we have made use of two of the four 16-bit ADCs provided in an EG&G digital lock-in amplifier (model 5209). According to the manual these ADCs have a nominal conversion time of 10 ms. The conversion can be started by applying a 5 V TTL signal to the ADC external trigger input provided in the lock-in amplifier. After conversion the output of each ADC was read using the IEEE488 interface. After reading, the peak detectors were reset by another TTL pulse lasting about 10 ms obtained from the PC.

The operation of the peak detectors must be synchronized with the firing of the laser. We have used these peak detectors with a Nd-YAG laser as well as a nitrogen laser. A silicon photodiode was used to detect the arrival of the laser pulse. The output of this photodiode was used to trigger a monostable multivibrator. The output of this monostable vibrator was a 5 V pulse lasting for several milliseconds. This circuit was carefully shielded and kept along with other circuits inside a Faraday cage. For sensing this signal and for supplying TTL pulses to the ADCs and the peak detector circuits, an interface board was built in our laboratory. This circuit[10] contains an Intel 8255 Parallel Peripheral Interface (PPI) chip which contains three 8-bit ports designated port A, B, and C. In our application this chip is configured such that the lower four bits of port C are outputs and the higher four bits are inputs. The signal indicating the firing of laser flash lamp is fed to one of these inputs. The control program, makes the computer wait for the trigger signal from the laser to arrive. Once this signal is detected, a pulse lasting approximately one millisecond is sent to trigger the ADCs. Since the peak detectors can store the peak for several tens of seconds without appreciable change in their value, delays due to jitter or A/D conversion do not cause any error. After allowing about 15 ms for the conversion to be completed, the result of conversions are read through the IEEE488 one by one. These values are processed as described in Sec. V of this paper and stored in a disk file. A longer pulse, lasting about 40 ms is then sent through the port to close the relays in the peak detector circuits. Thus the storage capacitors are discharged and the peak detector becomes ready for the next pulse. This cycle is repeated until the specified number of pulses are accumulated. The required delays were all generated by the software. In our experiments the pump laser produced pulses every 100 ms (10 pps). Thus processing of the data such as pulse selection and writing these data must be completed well within this 100 ms interval. Thus the program was written such that all the unnecessary overheads were avoided. For example, writing to monitor screen or a disk file takes a considerable amount of time. To avoid this delay, the data were stored in an array and only after the experiment was over were they passed onto the screen or disk file. This way more time is available for the processing.

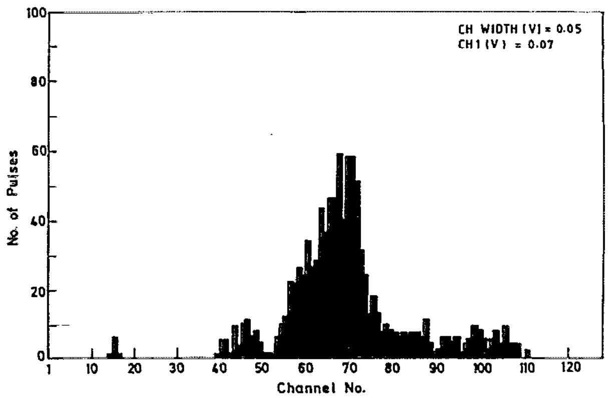


FIG. 5. Pulse-to-pulse stability of the second-harmonic beam of a mode-locked cavity dumped Nd-YAG laser monitored with the computer-controlled peak detector. Channel 1 corresponds to 0.7 V and the width of each channel is 0.47 V.

V. SOME TYPICAL APPLICATIONS

When optimizing the performance of any pulsed laser, one is often interested in the pulse to pulse stability of the laser. The computer-controlled peak detector described in this paper could be used to monitor the stability and the results could be displayed in the form of a histogram on the video monitor. A typical run of such an experiment is shown in Fig. 5. The laser used was a mode-locked, cavity dumped Nd-YAG laser (Continuum YG-601) operated at ten pulses per second. The histogram shown is for the second harmonic (532 nm) of the Nd-YAG laser. For this purpose a fast photodiode (Motorola MRD 510) was connected to the input of the peak detector. Care was taken to see that the photodiode was not saturated by using neutral density filters to attenuate the laser pulses. The computer was programmed to read the pulse heights for a specified number of pulses, which was 2000 in the present case. The data were transferred to memory after each shot and stored in an array. After the specified number of pulses, the data were sorted to give the frequency of occurrence of pulses within fixed intervals of voltage. The voltage range in which the photodiode's output is linear with intensity is divided into 120 channels. The number of pulses counted in each channel is plotted as function of channel number and displayed as shown in Fig. 5.

Amplified spontaneous emission (ASE) from laser dyes is usually studied by exciting dye media with intense pump pulses such as from a nitrogen laser. At low pump powers, the ASE intensity increases linearly with pump power. As the pump power is increased, gain saturation makes the ASE grow nonlinearly. In many experiments designed to study dye lasers the linear region is preferred. If the pulse to pulse fluctuation in the pump laser is very large, the system such as the dye laser may respond nonlinearly to the more intense pump pulses. We have used a pair of computer-controlled peak detectors simultaneously to study this saturation effect organic dye lasers. The experimental setup for producing

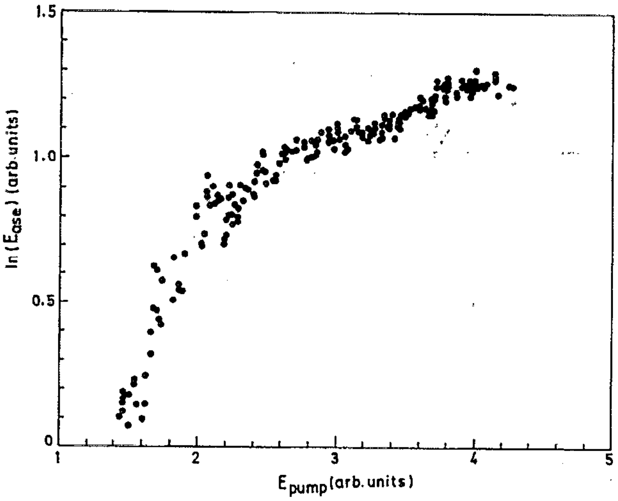


FIG. 6. Saturation of the amplified spontaneous emission with input pump power in a dye laser. E_{pump} and E_{ASE} are pulse energies of the pump and ASE pulses, respectively.

ASE pulses from organic dye solutions has been described in many papers[1–3] and therefore will not be elaborated here. The pump laser was a nitrogen laser built in our laboratory. This laser was specially designed for low rf emission and will be described elsewhere.

This laser produced intense UV pulses at 337 nm. These pulses shown in Fig. 1(a) typically had a width of 6 ns. In the experiment described here the repetition rate of the nitrogen laser was close to 10 Hz. The dye solution was prepared by dissolving Coumarin-481 laser dye (Exciton) in *n*-butyl acetate. The concentration was 5×10^{-3} mol/ℓ. By adjusting the gas pressure in the nitrogen laser channel, pulses with a wide range of energies were produced. One detector, monitored the UV pulses from the nitrogen laser. The pulses from this detector were also used to signal the computer of the arrival of the laser pulse. A PMT fixed to the entrance slit of a monochromator monitored the ASE pulses from the dye laser. The monochromator was tuned to the ASE peak wavelength (465 nm). The data were stored in an array as already explained and transferred to a disk file after capturing 1000 pulses. The plot of ASE pulses energy versus the pump energy is shown in Fig. 6. The saturation of ASE intensity for pulses of higher pump power is clearly visible in the graph.

By programming the computer to consider only pulses falling within specified upper and lower bounds of voltage, pulses lying in a narrow range of laser energy could be selected. Figure 7 shows such pulse selection. Figure 7(a) shows 1000 pulses as they are. In Fig. 7(b) pulse selection was effected by imposing the condition that the pulses have voltage greater than 3.8 V and less than 4.0 V. In our computer program, written in c-language, this was implemented by a simple "if" statement. In our experiments a second peak detector (negative peak detector), connected to a PMT, was used to monitor the amplified spontaneous emission from the organic dye. The data from this second peak detector were written into the array only if the pump pulse passed the test for upper and lower bounds mentioned above.

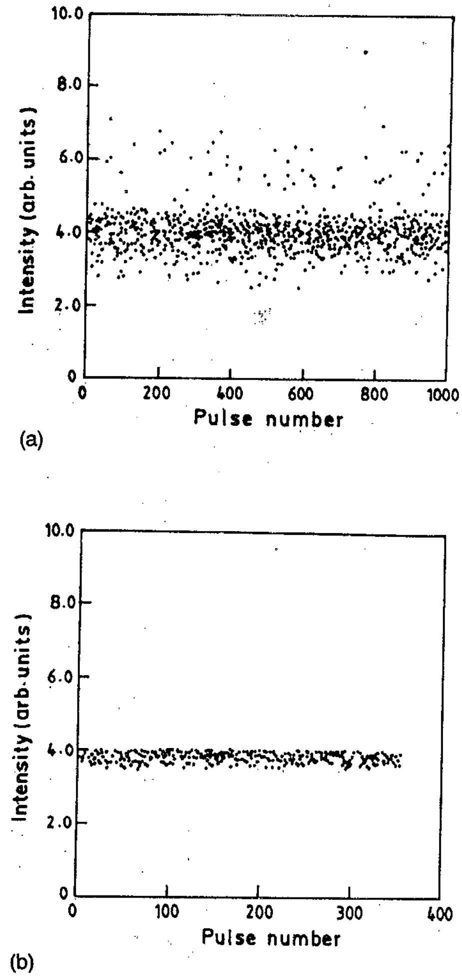


FIG. 7. (a) Shows the energy scatter of 1000 pulses from the nitrogen laser. (b) Shows the pulses selected by the computer when the on-line pulse selection is activated.

ACKNOWLEDGMENT

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