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# A peak power and energy monitor for pulsed lasers

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## Abstract

The details of design and fabrication of an instrument for monitoring the peak power and energy of pulsed lasers has been given here. It incorporates a peak detector, for sensing the peak power of laser pulses (duration $\geqslant 100$ ns), an integrator for detecting energy of pulses (duration $\sim 10$ ns) and two sample and hold stages for retaining the signal for long periods with negligible droop (50 mV for a 10 V signal in 10 secs). The important features of the instrument are : it can be fabricated easily, is inexpensive and can operate independently without the need for high speed storage instruments like oscilloscope, etc.

Key words : Pulsed lasers, optical instrumentation, photometry.

## 1. Introduction

Many kinds of experimental investigations use high power and/or high energy laser pulses of monochromatic radiation as probes. Some of these applications are in the measurement of temperature and specie concentrations by laser Raman scattering, ranging of targets, laser micromachining, annealing, etc. To obtain quantitative results from such experiments and also to monitor the variations in the output of the laser between pulses[1], it is necessary to measure the power and/or energy of each laser pulse. The duration of the laser pulses can vary from subpicoseconds for modelocked lasers to a few nanoseconds for Q-switched lasers to much longer ($\sim\mu$s to ms) for normal running lasers[1]. Measurements of the power of laser pulses with such fast rise times and short duration requires ultrafast detectors followed by an instrument capable of making a permanent or quasi-permanent record of the detector output[2].

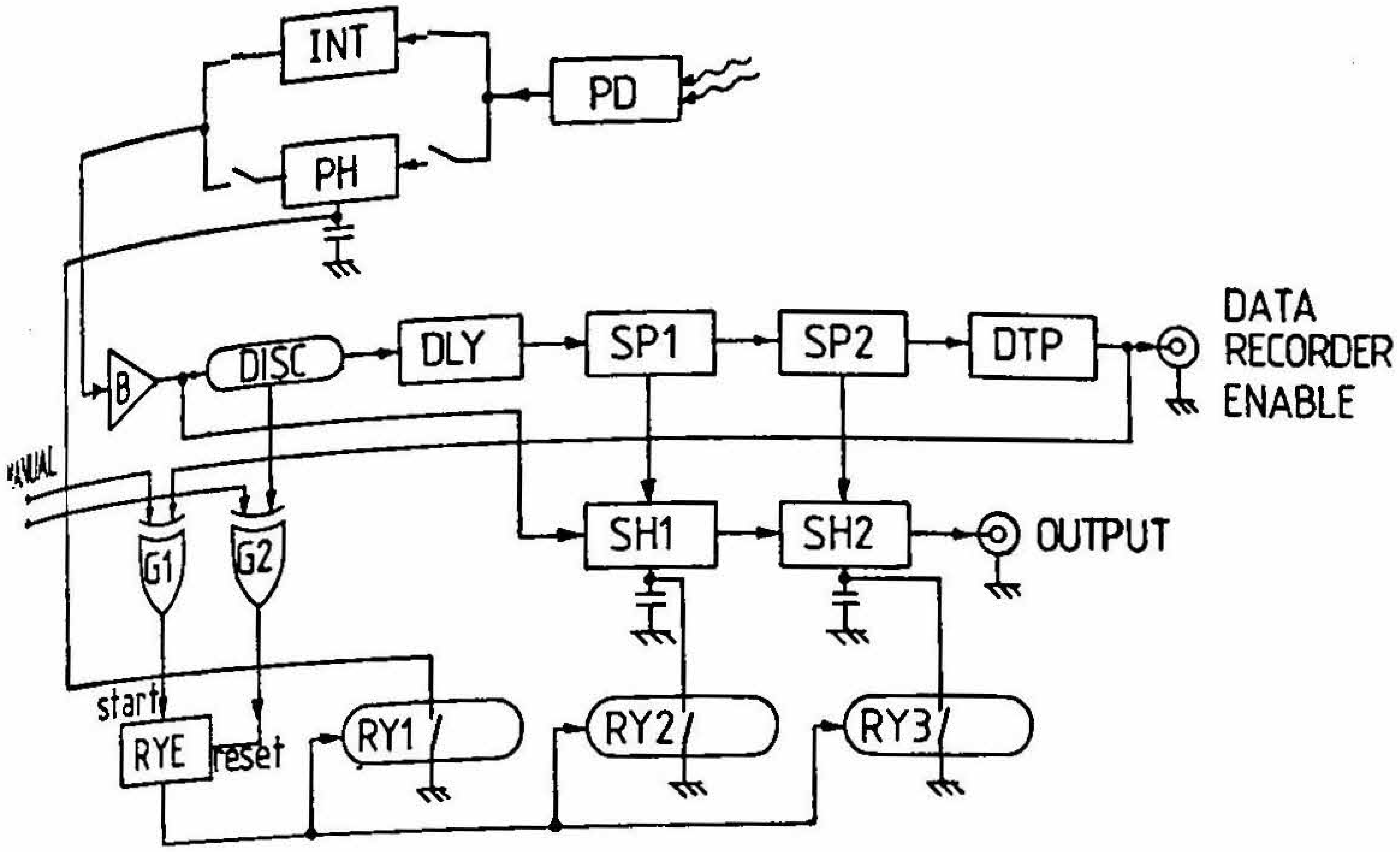
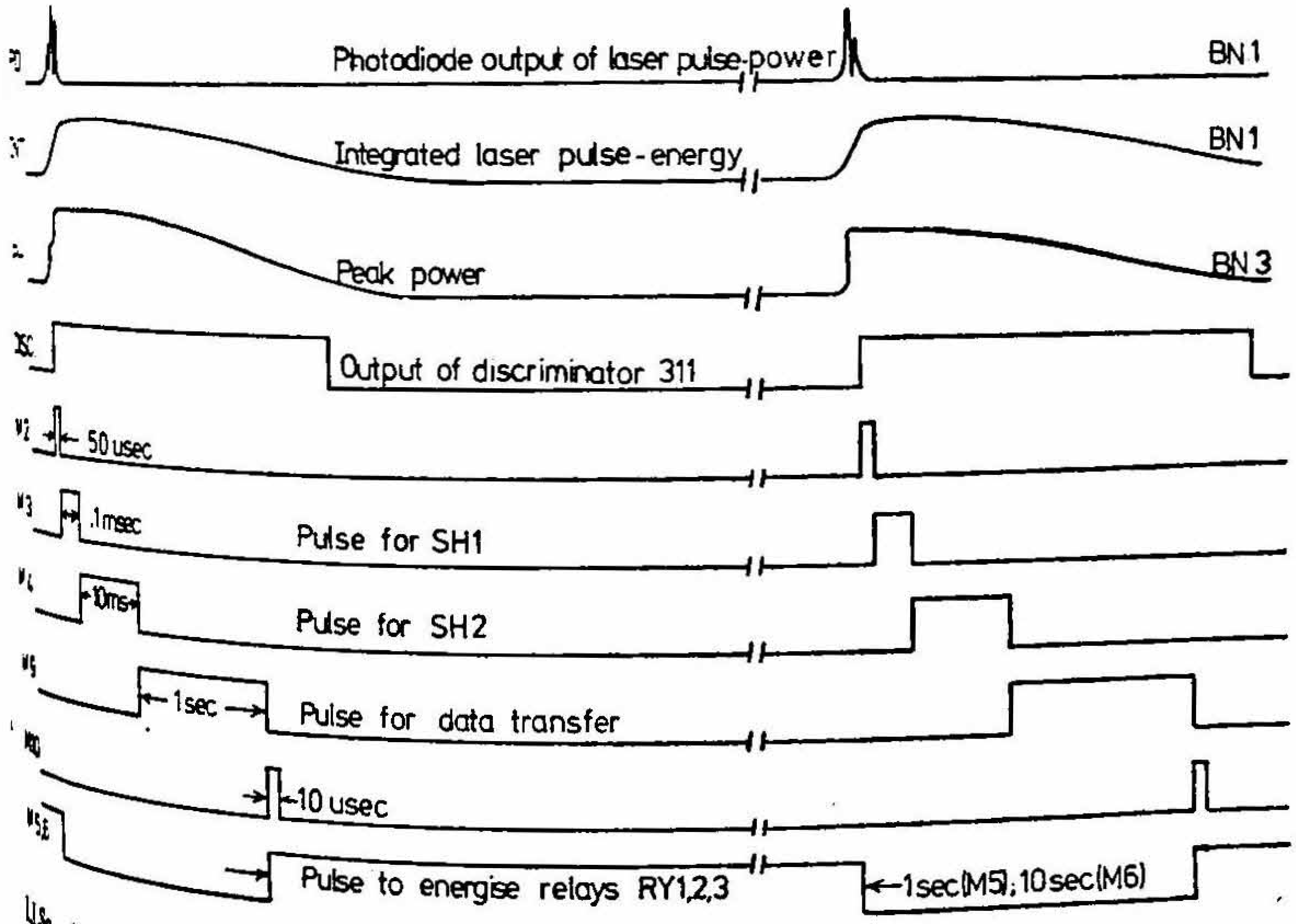


Fig. 1. Schematic diagram of laser energy and peak power monitor. B = Buffer amplifier; DISC = Discriminator; DLY = Delay pulse; DTP = Data transfer pulse; G = Exclusive OR gates; INT = Energy integrator; PD = Photo detector; PH = Peak holder; RYE = Relays enable pulse; RY1,2,3 = Reed relays; SH1,2 = Sample hold; SP1,2 = Sample pulses.



analog switches which enable the capacitors C4 and C5 of the sample and hold circuits to be charged. The first switch allows the charging time to be 0·1 ms whereas the second one allows it for 10 ms. The data at the output of the second sample and hold circuit is transferred to a recorder in a few seconds after which the capacitors C3, C4 and C5 are all discharged. The pulse operating a reed relay to discharge these capacitors can be terminated either manually or by the leading edge of the signal from M2 (reset pulse to M5 & M6 = $\overline{M2}$) thus enabling the device to accept the next measurement.

In the energy monitor mode, the photodetector output is taken first to a capacitor which integrates the detector output. This output signal is then fed to the same buffer amplifier, discriminator and sample and hold circuits.

## 3. Circuit description

Figure 3 shows the circuit diagram for the peak power and energy monitor. A silicon photodiode (EG & G, SGD 100) with spectral response in 300-1130 nm region is used for detecting the laser pulse. Switch WS1 provides three sensitivity ranges in the power (resistive termination) and two ranges in the integrate or energy mode (capacitive termination).

The output signal from the detector assembly (BNC socket BN1) is fed to the input of the circuit (BN2) through a switch WS2 that selects the peak power or energy monitor mode. The peak holding circuit comprises a high speed FET operational amplifier A1 (Datel 103 B) with a gain band width of 50 MHz at unit gain used as a peak detector and a FET amplifier A2 ($\mu$A 740) used as a voltage follower. The capacitor C3 (220 pF) in combination with A2 holds the peak voltage and the output of the peak holder is available at BN3. This output is then taken through sample and hold circuits (comprising comparator A3, amplifiers A4, A5 and gates F1, F2 as described below) to stretch the peak for taking it to a slow recording device.

In the energy monitor mode the output of the photodiode is taken to an integrating capacitor (C1 or C2), and then through the switch WS2 to the voltage follower A2 for impedance matching. A voltage comparator A3 ($\mu$A 311) gives a TTL compatible signal whenever the input voltage exceeds an adjustable reference voltage (front panel potentiometer R11) to buck out such d.c. voltage that may be present at the output of the photodiode in the quiescent state. An indicator (LED L1) lights up whenever A3 output is high. Next the output of the voltage comparator is fed to the input of the first one M1 ($\frac{1}{2}$ of 74123) of a series of eight monostable multivibrators (74123) M1 to M6, M9 and M10. M1 triggers at the first leading edge of A3 and gives a pulse of 1 second duration. This is employed to take care of jitter in A3. The other monostables provide the necessary gating pulses for sample and holding, energising relays etc., with time delays as shown in fig. 2.

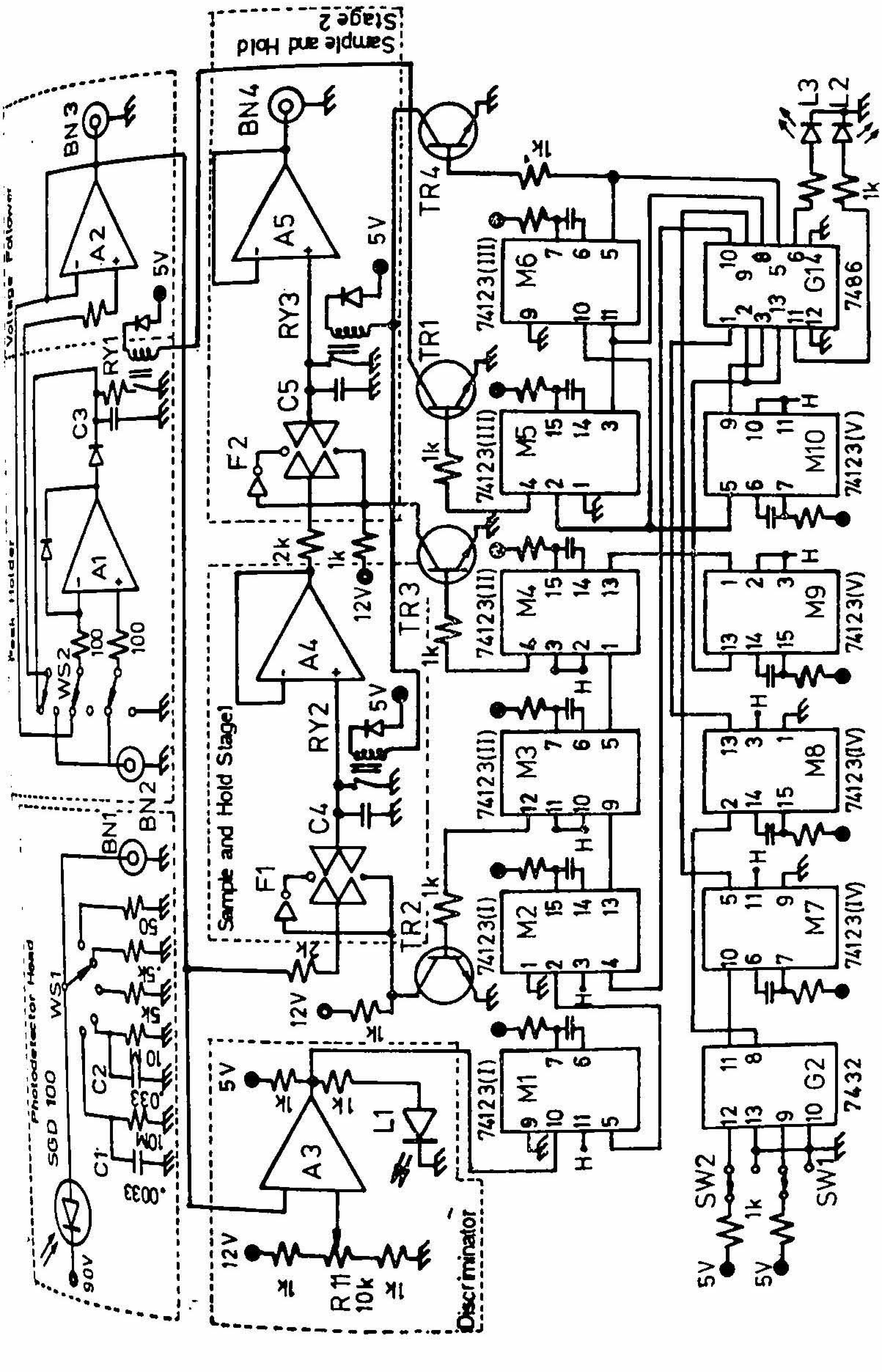


FIG. 3. Circuit diagram.

The signal from A2 is also taken to a sample and hold circuit comprising an analog switch F1 (CA 4066) and amplifier A4 ($\mu$A 740). F1 is gated for 100 $\mu$s by the output of M3 such that C4 (0·015 $\mu$F) is fully charged within this gating time. Analog switch F2 (CA 4066), capacitance C5 (0·1 $\mu$F) and amplifier A5 ($\mu$A 740) form the second sample and hold circuit fed by A4. M4 provides the gate pulse (10 ms) for the switch F2. Monostable M9 provides the time delay to transfer the data at the A5 output (BN4) to a recording device.

The capacitors C3, C4 and C5 can be discharged either manually or automatically. In the automatic mode, the output of M9 triggers M10 (through G1-7486) and the M6 which in turn activates a transistor Tr4 to energise the reed relays RY2 and RY3 (OEN 52) that discharge the capacitors C4 and C5 for a period of 10 seconds. Output of M10 also triggers M5 to energise RY1 (OEN 52) which discharges C3 for a period of 1 second. M5 and M6 are reset by the output of M2 taken through gate G1 so that a new cycle is started as soon as there is an input laser pulse. Two indicators (LED L2 and L3) indicate the data transfer and capacitor discharge periods.

Capacitors C3, C4 and C5 can be discharged manually by the switch SW1 and before starting a new cycle, the instrument can be reset by a second switch SW2. Contact bounce of SW1 and SW2 is eliminated with monostables M7 and M8. ±12V supply has been used for all the components except the analog switches F1 and F2 which have 15V supply to ensure their safety.

## 4. Performance

The peak power and energy in laser pulses from a flash lamp pumped dye laser (operating at 590 nm) and also a free running pulsed Nd-YAG laser (1060 nm) have been measured by the instrument described above. The photodiode SGD-100 has been used in the photoconductive mode by reverse biasing it. It has a nanosecond response time and is linear over a $10^7$ range of light input. The operational limit of the photodiode is set by the maximum power that it can absorb before being damaged. These correspond to radiation flux of 4·8 W/cm$^2$ for short pulses and 40 mW/cm$^2$ for continuous sources at a wavelength of 900 nm where the photodiode has the maximum spectral response.

Since the photodiode output is linear it is possible to use it for relative power and energy measurements directly without any calibration over a large range of input powers and energies. To obtain absolute values, however, the photodiode was calibrated using a secondary standard of spectal irradiance (a calibrated tungsten halogen lamp whose calibration is traceable to NBS primary standards) and a monochromator. Experiments carried out showed that the instrument was linear over its entire operating range. The minimum measurable power and energy with this instrument are about

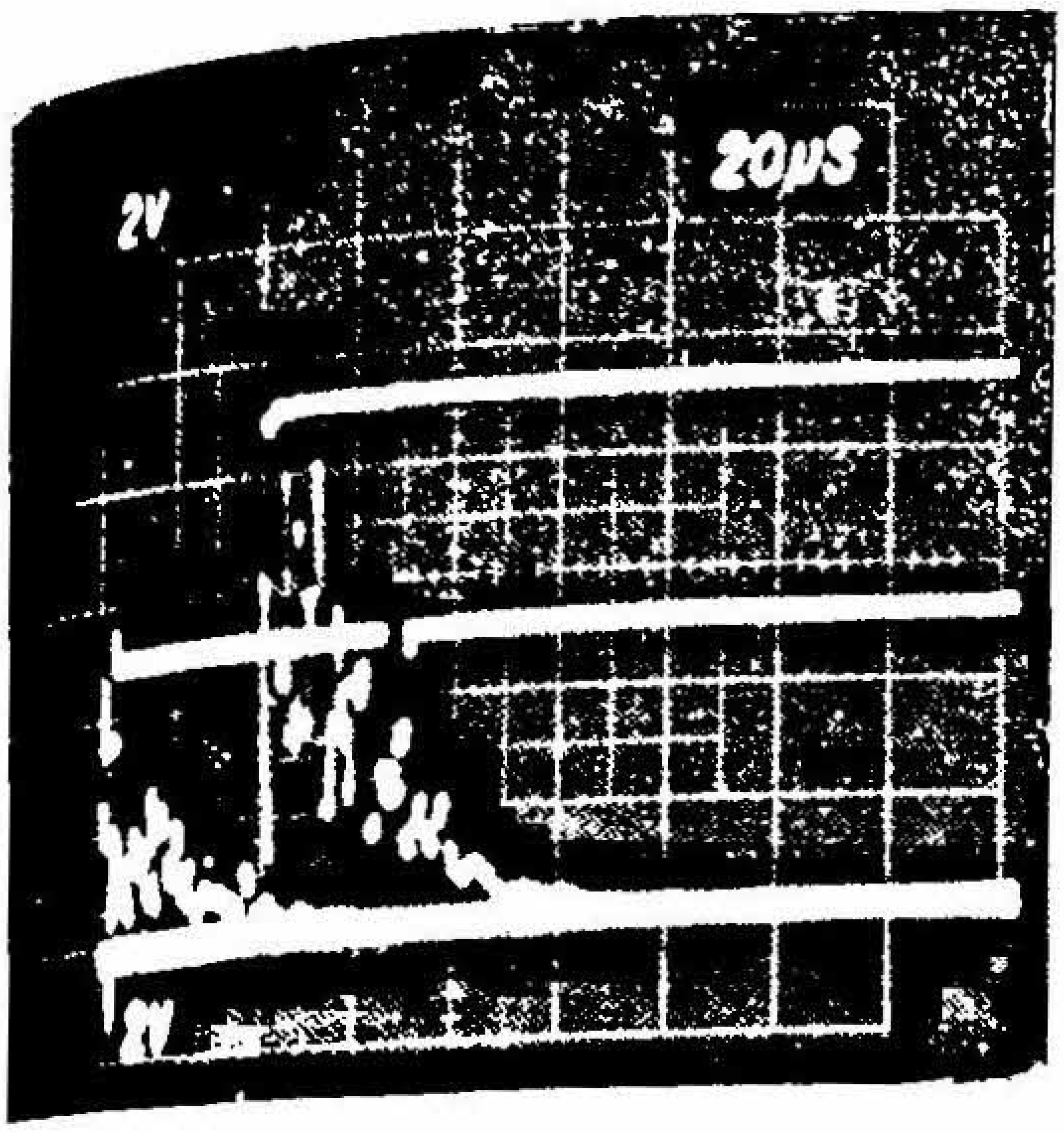


FIG. 4. Oscilloscope traces of Nd : Glass laser pulse output directly from photodiode and from the peak holder. Two sets of traces corresponding to two pulses of different magnitudes are shown. The laser pulse has many peaks but the largest peak has been held by the peak holder as required.

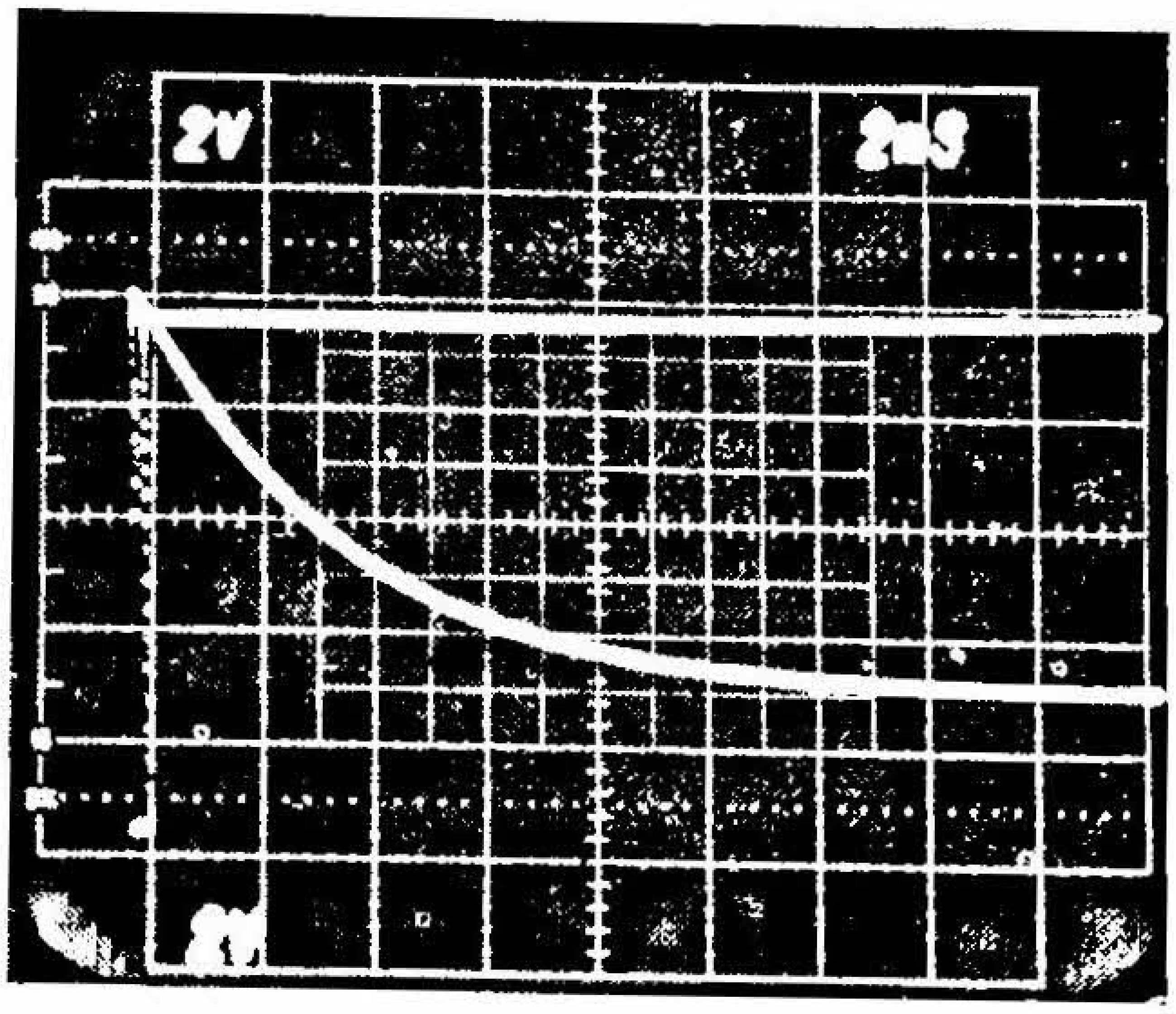


FIG. 5. Oscilloscope traces of an Nd : Glass laser pulse from the photodiode in energy mode and output of energy monitor (the flat trace at top).

40 $\mathrm{mW/cm^2}$ and 0·1 $\mu\mathrm{J/cm^2}$ which correspond to a setting of 1 volt as threshold of the comparator.

Figures 4 and 5 are oscilloscope traces of laser pulses from the Nd-YAG pulsed laser. In these figures, the lower trace corresponds to the direct output from the photodiode (BN1) and the upper trace is the output from the monitor (BN4). It can be seen that the peak power and the energy detected by the monitor is within an accuracy of 0·1% when compared to the direct photodiode output. The main advantage of this monitor is that the detected quantity is stored for an extended period (over several seconds) and the voltage droop is less than 5 mV/sec at the output.

The time delays and gating periods shown in fig. 2 have been chosen for proper performance here and can be changed to suit the needs of the experiments. For example, the duration of M2 is taken to be 50 μs assuming that to be of the order of the laser pulse width so that the total laser energy is sensed in the integrating capacitor before it is sampled. The sampling time for the first sample and hold unit is set at 100 μs (acquisition time for 10V to 0·1% is 10 μs) for fully charging the capacitor C4 (0·015 μF), while the second sample and hold unit is gated for 10 ms to charge C5 (0·1 μF) fully (acquisition for 10V to 0·1% is 150 μs). The values of C4 and C5 are chosen to have the smallest voltage droop (approximately 20 mV/s and 2 mV/s respectively) consistent with the voltage acquisition. If a longer duration for data transfer is desired it is possible to stretch the pulse M5 since the voltage droop is not considerable over as long a period as 10 seconds (less than 50 mV at a 10V level).

## 5. Conclusions

The rise time of the peak detector was found to be about 70 ns. For detecting the peak power of Q switched lasers with pulse widths under 100 ns, an amplifier with bandwidth larger than the 103 B used here is required.

The acquisition time of the sample and hold stages are somewhat long because of the current limitations of the switches $F_1$ and $F_2$. This can be overcome by using either switches with larger current capacity or sample and hold modules with fast acquisition times. As has been indicated earlier the instrument has been designed and fabricated using commonly available components and substituting them with sophisticated components the performance can be improved very easily without making any basic changes.

The peak power and energy monitor as described here has been constructed in two modules, with the photodetector and its termination in a detector head, while the rest of the circuit (comprising two printed circuit cards) is housed in a two-width NIM (Nuclear Instrumentation Module).

## References

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## Editor's Note

During the review process it was pointed out that this paper contained extensive description of the circuit details and operation. Normally such details need not be included in a climate where extensive electronic instrumentation is commercially available. The paper is, however, published in its present form as it would 'enable the fabrication of such an instrument with minimum complexity and utilising locally available components.'