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# Power and Energy Measurement of Repetitively Pulsed Lasers

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# NBS TECHNICAL NOTE 398

ISSUED MARCH 1971

Nat. Bur. Stand. (U.S.), Tech. Note 398, 10 pages (March 1971)
CODEN: NBTNA

# Power and Energy Measurement of Repetitively Pulsed Lasers

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This research was partially supported by the Advanced Research Projects Agency of the Department of Defense under ARPA Order No. 891.

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# Power and Energy Measurement of Repetitively Pulsed Lasers

D. A. Jennings

The problem of measuring average power, energy per pulse, and peak power of some of the more common repetitively pulsed lasers is discussed. The techniques which have been used at the National Bureau of Standards are mentioned along with some of the accuracies obtained. Accuracies of 3 to 10 percent can be achieved, depending on the laser source and the parameter of interest.

Key Words: Average power; energy per pulse; laser; peak power; repetitively pulsed lasers.

As is often said, the measurement of laser power is a straightforward problem with straightforward solutions. The purpose of these words of wisdom is to point out some techniques that we have found useful and some precautions that are important to observe.

The problem of power measurement is overwhelming, to say the least, in the sense of the ranges to be covered. For example, wavelengths from 300nm to 300μm, average power levels from microwatts to tens of kilowatts, peak powers from milliwatts to megawatts, repetition rates from 1 to 5000 pulses per second and pulse widths of 100μs to 10ns are typical ranges one must contend with. However, one can do a reasonable job for some lasers at some power levels: diode lasers around 900nm, Nd:YAG lasers at 1060nm and $CO_2$ lasers at 10.6μm, to name a few.

Some of the things we would like to know about laser pulses are (1) the average power, (2) the peak power, and (3) the energy per pulse. Several publications deal with the subject of laser energy and power measurements.[1] [2] [3] We have found two methods particularly useful for average power levels of 0.1 to 30 watts: (1) the timed shutter and liquid cell calorimeter method which can give an accuracy of around ±4% [3]; and (2) the disk calorimeter which is very good for large diameter beams, and can give an accuracy of around ± 3%.[4] The peak power of the laser pulse must be less than that which will damage the measuring device. Typical safe magnitudes for incident power densities for 30ns laser pulses, are $10^8$ watts/$cm^2$ for the liquid cell calorimeter, and $10^5$ watts/$cm^2$ for the disk calorimeter.

The measurement of the energy per pulse is no doubt the easiest to measure since

$$\text{Energy/pulse} = \frac{\text{Average Power}}{\text{Pulses/second}} .$$

The accuracy of this technique depends on (1) the energy/pulse stability of the particular laser system and (2) the knowledge of the repetition rate. The accuracy of the energy per pulse is certainly not better than the average-power measurement.

The peak power in the pulse is by far the most difficult thing to measure, and, as in every kind of measurement, it depends on how much detail one insists on knowing. The peak power is obtained from measurements of the total energy and the temporal distribution of the pulse. For example, consider the two pulse shapes as shown in figures 1 and 2. The peak power of a laser pulse, as shown in figure 1, can be measured though the measurement requires care. A laser pulse with a shape as shown in figure 2 is not so nice, and in some cases, the sub-pulse width may be as small as $10^{-12}$ s. The question is "What can we measure?". On the assumption we have a well behaved pulse, i.e., no substructure, we can measure the energy per pulse. We also know that

$$E = \int_{o}^{\infty} p \, dt \quad ,$$

where E is the energy in the pulse and p is the instantaneous power. So if we have a linear power detector, in principle we can work back to obtain the peak powers. In what follows, we describe two methods for measuring the peak power.

As our first example, assume (1) we have a setup whereby we can monitor the laser pulse with a suitable fast detector to obtain the temporal behavior of the instantaneous power and (2) that we have recorded the temporal behavior of the laser pulse intensity and the energy. (It is assumed the reader is familiar with pulse circuitry). We will have a photograph similar to figure 3. Let the area under the laser pulse be A, and the area of one of the grids be a. We know that:

$$A = \beta E$$

or

$$\beta = \frac{A}{E}$$

where $\beta$ is the constant of proportionality.

We also know that $$a = \beta p' t$$

or

$$\beta = \frac{a}{p' t}$$

where t is the time per division and $p'$ is the instantaneous power/per division.

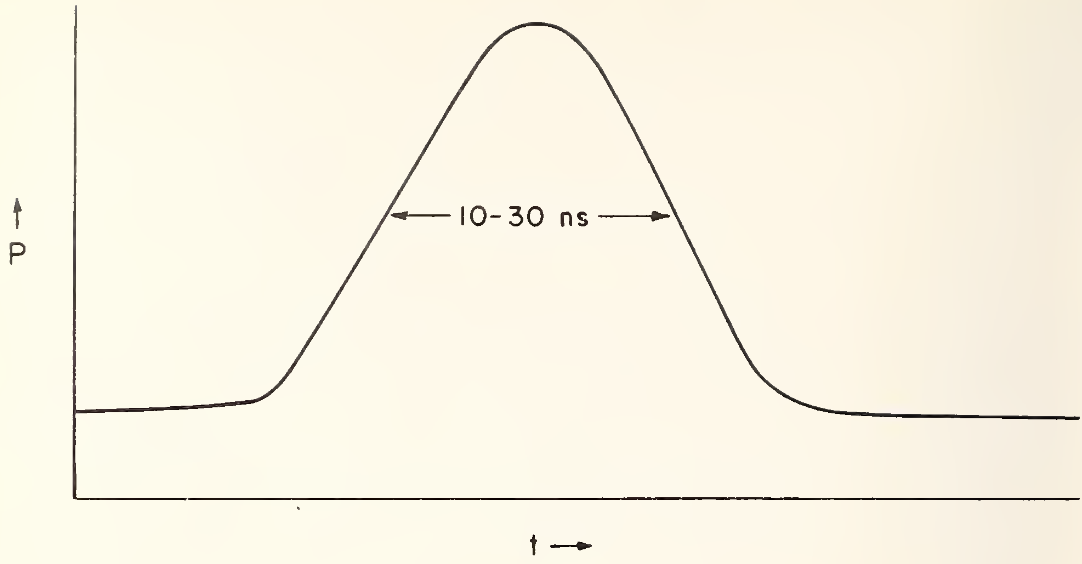


Figure 1. Temporal distribution of a well behaved Q-switched laser pulse.

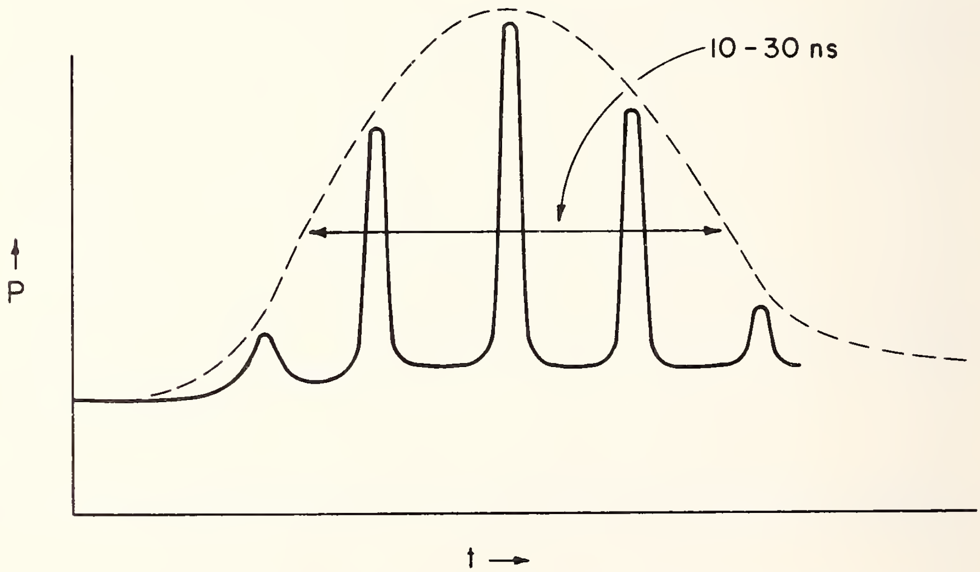


Figure 2. Temporal distribution of a Q-switched laser pulse which contains substructure that may not be seen by the detector.

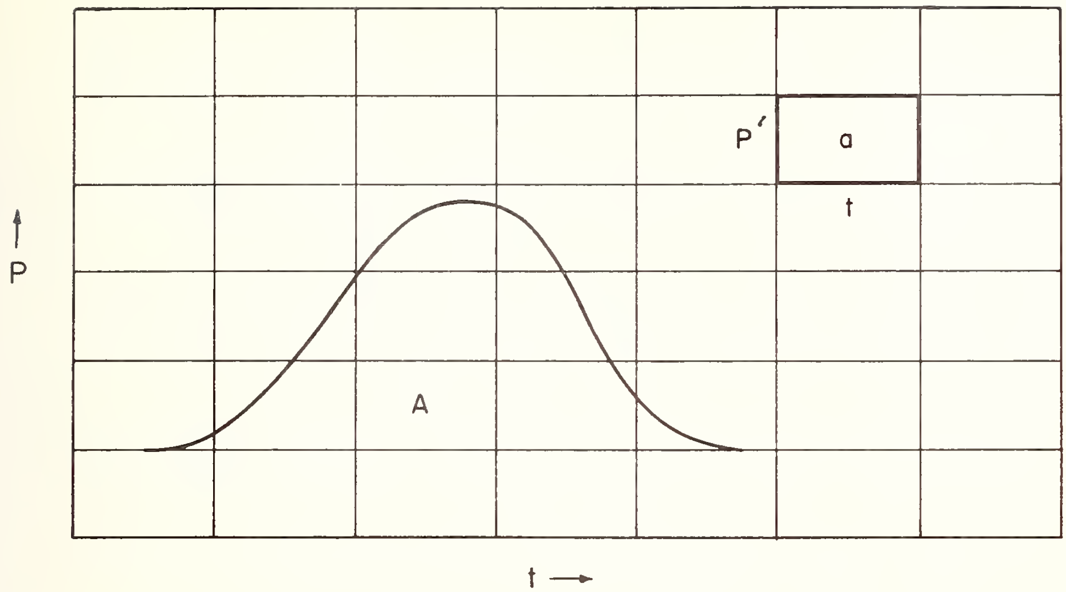


Figure 3. A representation of a typical oscilloscope photograph of the temporal behavior of a laser pulse, from which we may obtain the peak power.

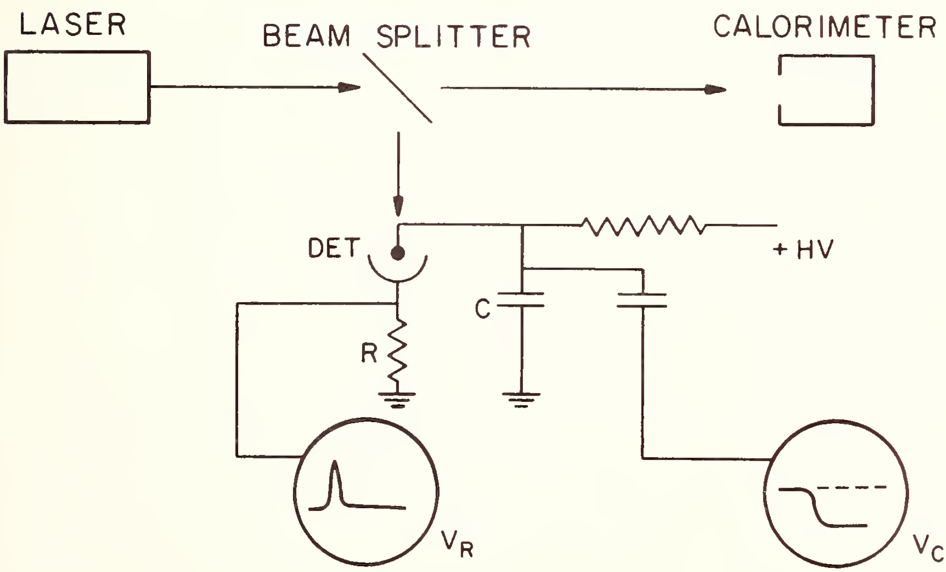


Figure 4. Schematic and apparatus setup for calibration of a peak power measurement.

So

$$\frac{a}{p' t} = \frac{A}{E}$$

or

$$p' = \frac{Ea}{At}$$

and the peak power, $P_o$ is the number of divisions times $p'$. The ratio of $a/A$ can be found by the use of a planimeter or one may actually cut out the grid and the laser pulse from the photograph and weigh them.

As our second example, consider the experimental arrangement as shown in figure 4. Again the detector is sufficiently fast and we can measure the energy per pulse. A simple circuit analysis will tell us how the circuit works.

We assume a linear detector, i. e., the instantaneous current is proportional to the incident power, and we write:

$$i = \alpha p$$

and

$$\int i \, dt = \alpha \int p \, dt$$

or

$$Q = \alpha E$$

and

$$i = \frac{Q}{E} p .$$

Now

$$i = \frac{V_R}{R} , \quad Q = CV_c$$

combining we have

$$\frac{V_R}{R} = \frac{CV_c}{E}$$

or

$$P_o = \frac{V_R}{RCV_c} E .$$

We note here that $E/RCV_c$ is a constant, namely $\frac{1}{R\alpha}$. Therefore, we need to measure it only once, and if E is the energy as measured by the calorimeter, then the power that is measured is that which is transmitted through the beam splitter; that is, we really have a power monitor.

Several words of caution are due. Since the energy measuring device measures the total beam, one must assure himself that the monitor detects a fraction of the total beam. Since some detectors are not uniform in response over their surface, we must also be assured that this effect is suitably averaged out. If a beam splitter is used care must be taken to eliminate interference effects, possibly by using a wedge-type splitter. Care must be exercised to take into account the polarization properties of beam splitters. Diffuse attenuators must be used carefully because of "speckle patterns" and the non-Lambertian nature of diffusers.

After taking all of these precautions, and more, the accuracy of the above methods is probably no better than ± 10%.

We have tried to describe some useful techniques for the measurement of average power, energy per pulse, and peak power for repetitively pulsed lasers, plus some things to avoid. The techniques for peak power measurements are good only for the response time of the detector. The measurement of subnanosecond pulses is another story.

The author would like to thank Drs. E. D. West and R. L. Smith for their very helpful comments.

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