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USE OF LEDS AS YAG LASER SIMULATORS

by

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There is considerable interest in using 1060 nm, light emitting diodes (LEDs) to calibrate detectors designed for measuring weak, diffuse YAG laser beams. This is so largely for reasons of cost and convenience. For example, a laser beam in the laboratory may have to be attenuated by as many as 14 orders of magnitude to reduce it to the right level; eliminating stray light is alone a formidable problem.

Questions naturally arise as to whether or not the use of the LED is theoretically or practically justifiable -- the degree of coherence differs from that of a laser, speckle may be a factor, other unsuspected obstacles may arise. The purpose of this paper is to examine the problem in some detail and to determine if possible the conditions under which suitably filtered and processed LED radiation may be used to simulate the laser beam.

We begin by asking, What are the potential differences? To answer the question, I have compiled a list of parameters that will have to be examined. The list, presented as Table 1, is intended to be as exhaustive as possible, even though some entries may be dismissed out of hand.

Apparatus

I used six LEDs whose wavelength was nominally 1060 nm and excited them with a signal generator that could provide electrical pulses up to 2 A and as short as 20 ns.[1,2] The radiation is detected by an avalanche photodiode, usually followed by a transimpedance amplifier and often by a radio frequency amplifier as well. Data were taken by connecting the horizontal and vertical outputs of a sampling oscilloscope to an xy recorder; the vertical output was filtered with a capacitor to reduce noise.

Sometimes, the oscilloscope was set on manual and the x axis of the recorder was driven instead by a transducer connected to a mechanical translator or a monochromator.

The rest of this paper is organized parallel to Table 1.

Wavelength

The YAG laser emits light at 1064 nm, with a linewidth of about 0.5 nm; the LEDs are not specified for 1060 nm precisely but display a peak in the neighborhood of 1060 nm, with a linewidth of about 50 nm. In addition, the peak wavelength of the LED is temperature dependent, so there is the possibility of a chirp during the evolution of a pulse.

To assess these problems, I excited the LEDs with 2 A, 20 ns pulses, set the oscilloscope on manual, and recorded spectra at various times during the pulse. The spectra showed no sign of chirping, even with pulses as long as 1 μs. However, the peak wavelength of all six LEDs was 1045-1050 nm, not 1064. This can be a serious problem if the LED is to be used with an instrument that contains a silicon detector; if the light is unfiltered, a calibration may be in error by as much as 10 percent owing to the wavelength difference only.

More important, however, is the likelihood that the receiver will contain a narrowband filter. In that case, the LED radiation should, in principle, pass through a filter that has an even narrower passband. Most of the radiation from the LED is sacrificed, and possibly the transmitted power will be insufficient; then, a broader band filter will have to be used and a correction factor calculated. For example, if the LED's filter and the receiver's filter are identical, the correction factor is about 0.35.[1]

Temporal Coherence

The linewidth of a source determines the temporal coherence of the radiation. The linewidth of the YAG laser is of the order of 0.5 nm, that of the LED up to 100 times greater, depending on filtering. Thus, it may be argued that the greater coherence length of the YAG laser will cause effects that are not present when the LED source is used.

The most serious effect will likely be interference due to multiple reflections in a thin, flat element such as a metal coated filter. If the light is coherent, the transmittance of such an element may be shown to be

$$T = \frac{T_1 T_2}{(1-R)^2} \frac{1}{1 + F \sin^2 \phi/2}, \qquad (1)$$

where T and R are transmittance and reflectance, the subscripts refer to the two surfaces, $R = \sqrt{R_1 R_2}$, $\phi = 4\pi nd/\lambda$ is the round trip phase shift through a slab whose thickness is d and whose index is n, and $F = 4R/(1-R)^2$. Figure 1 shows the results of some calculations for $R_2 = 0.04$ (glass with $n = 1.5$) and various values of R_1. The dashed lines labeled "incoherent" represent the transmittance calculated for incoherent light, yet taking multiple reflections into account. The error resulting from interference may be as high as ± 50 percent when R_2 exceeds 0.9 or so.

Thus, if they are not volume absorbers, the attenuators used in laser systems should be wedged enough for nd to change by at least $\lambda/4$ across the diameter of the beam, or they should be very thick compared to the coherence length of the source.

If a source has a Gaussian spectral line whose width (measured for convenience between the points where the intensity is 1/e of the maximum) is $\Delta\nu$, then the degree of coherence drops to 1/e when the optical path difference between two beams is $(2/\pi\ \Delta\nu)$. For the YAG laser, this is about 2 mm. Therefore, parallel plates may be used, provided that their optical thickness nd exceeds, say, 4 to 5 mm.

Beam Divergence

If an incoherent source is placed precisely at the focal point of a diffraction limited lens, the beam refracted by the lens will be collimated but will still exhibit a small divergence, as the result either of diffraction or of the finite size of the source. In either case, we call this residual divergence "the beam divergence"; it is distinguished from the divergence of an uncollimated beam. The beam divergence of an LED simulator is important because the receiver may be set up to accept angular field of view as small as 0.5 mrad or less.

The beam divergence is determined by the geometry of the LED and the collimating lens or mirror. For example, a 0.1 mm LED collimated by a 50 cm lens yields a beam divergence of 0.2 mrad.

It may be difficult to measure the beam divergence directly, but it is simple to calculate it from a knowledge of the size of the source. Unfortunately, when I performed point-by-point scans of the LEDs, I found that, in general, their radiant areas were in effect several times larger than the manufacturers' specifications; see Table 2. This was so in one case because the diodes, which were ostensibly surface emitters, emitted primarily from their edges; this light was reflected by the surroundings and contributed more power than the light emitted from the surface. A scan of one such LED is shown in Figure 2. A second manufacturer's LED is contacted to a ruby lens to increase power in the forward direction; the scans of these LEDs showed a diameter equal to that of the lens, which suggests that the lens scatters somewhat. One such scan is shown in Figure 3.

Provided that the lens is sufficiently aberration free, the beam divergence may be calculated from this type of scan; the result will be several times larger than what is calculated from the specifications.

Spatial Coherence

The LED radiation will be spatially incoherent, provided that the LED (or whatever spatial filter is used) is large compared with the resolution limit of the collimating lens; this will almost always be so. What about the laser light scattered from the object? The beam divergence and range determine the size of the illuminated area; this, in turn, determines the speckle pattern that falls onto the receiver. The size of the speckles is, on average, about 1.6 $\lambda L/D$, where L is range and D is the diameter of the scatterer.[3] If there are many speckles within the lens aperture, then the light may be considered spatially incoherent for many purposes. By way of example, if a 10 cm lens is located 10 km from a scatterer, then the number of speckles within the aperture is about 900, and the light is spatially incoherent.

Incidentally, speckle has another effect on the laser receiver. In our example, the number of bright speckles is 900/2, or 450. As a result, the relative fluctuation from shot to shot will be about $1/\sqrt{450}$, or 5 percent.[4] Fluctuations with this origin will not exist with an LED source.

Pulse Duration and Shape

The pulses emitted by a Q switched laser may have a duration of 10 to 50 ns or more, frequently with the trailing edge longer than the leading. I have easily obtained LED pulses as short as 20 ns, and Franzen and Day of this laboratory have shown how to generate 2.5 ns pulses with similar diodes.[2] The precise shape of the pulses should not be important, since the receivers will most likely be some form of energy or peak power detector. Therefore, there seems no reason to believe that the time domain properties of the LEDs will be a hindrance, as long as the electrical bandwidth of the detection circuitry is sufficiently great.

Energy Density and Uniformity

The uniformity of the beam across the lens will not necessarily be affected by the nonuniformity of the source radiance. To assess the beam profile, I roughly collimated the radiation with a 20 cm, f/2 lens and scanned across a diameter of the lens. (This procedure does not measure the radiation pattern as a function of angle because the detector is not constrained to a circle; rather, it measures the more relevant (for us) irradiance across the exit pupil of the lens.) Figures 4 and 5 show the results of several such scans. The LEDs that do not use lenses show approximately uniform irradiance across the entire f/2 aperture; the LEDs with the ruby lenses are uniform to 5 percent or so within an f/8 aperture.

Summary and Conclusions

There is no reason in principle that an LED may not be used to simulate a diffusely reflected laser beam with certain properties. The most important practical problem may be generating sufficient energy per pulse at the proper wavelength.

Much of the material presented here has been reported in more detail in Reference 1. That reference also contains appendices on the transmittance of a bandpass filter, depth of focus of the LED collimating lens, lens aberrations, and interference filters. Detailed design of a system is, of course beyond the scope of either paper.

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References

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2. D. L. Franzen and G. W. Day, "LED Source for Determining Optical Detector Time Response at 1.06 μm," Rev. Sci. Instrum. 50, 1029-1031, 1979.

3. M. Young, Optics and Lasers, Springer-Verlag, New York, 1977, chap. 4.6; M. Young, et al., "Resolution in Optical Systems Using Coherent Illumination," J. Opt. Soc. Amer. 60, 137-138, 1970.

4. M. Young and R. A. Lawton, Measurement of Pulsed-Laser Power, NBS Technical Note 1010, 1979, sect. 3. Availabile from Supt. of Documents, U.S. Government Printing Office, Washington, DC 20402, stock no. 003-003-02028-1.

Table 1.

Potential Areas of Difficulty

I. Wavelength
  a. Wavelength of maximum power
    1. Detector responsivity vs. wavelength
  b. Linewidth
    1. As it relates to (a)
    2. Coherence length
  c. Chirping of LED

II. Beam Divergence
  a. Degree of collimation of simulator, compared with laser return
  b. Spatial coherence

III. Pulse duration and shape

IV. Energy density over aperture
  a. Uniformity over aperture
  b. Pulse-to-pulse energy

Table 2.

Luminous Diameters of LEDs (μm)

	Specification	Actual
A1	450	1700
A3	450	1600
B1	400	400
C1	100*	550
C2	100*	560

* 180 if effect of ruby lens is included.

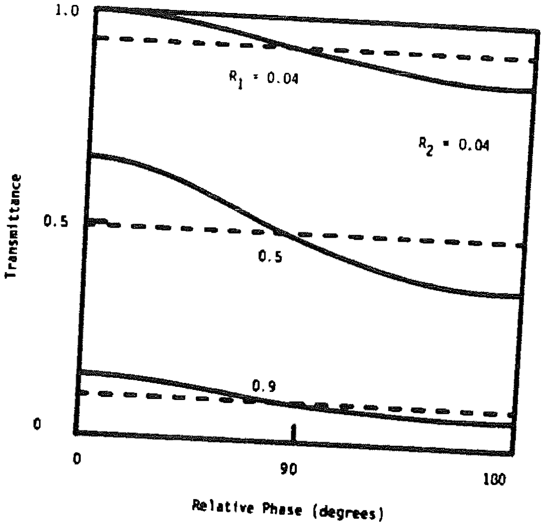

Figure 1. Transmission of metal coated filter with R_2=0.04 and R_1 as shown.

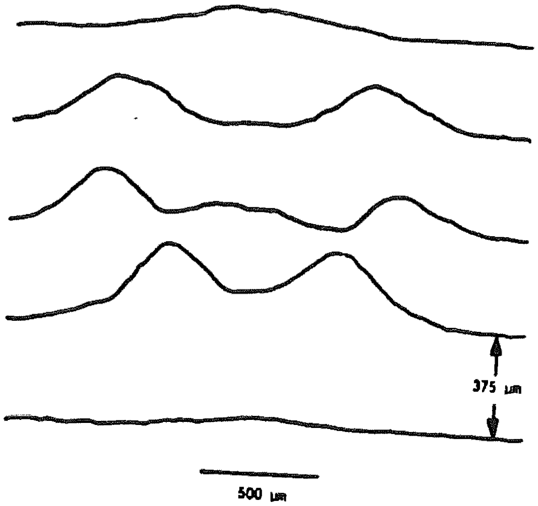

Figure 2. Near field scan of LED A3.

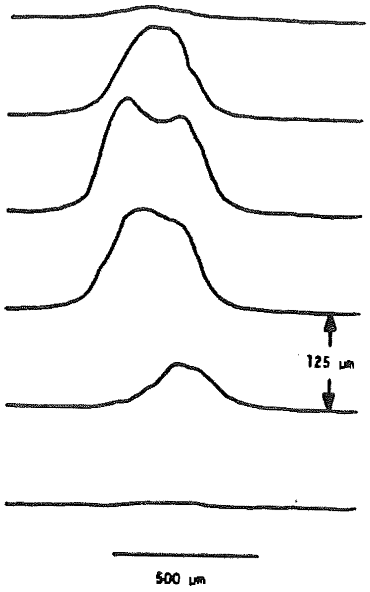

Figure 3. Near field scan of LED C2.

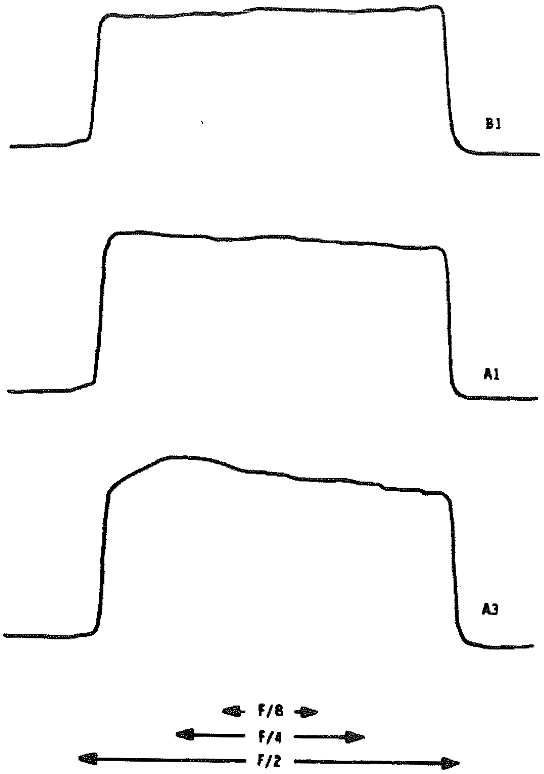

Figure 4. Exit pupil scans of three LEDs.

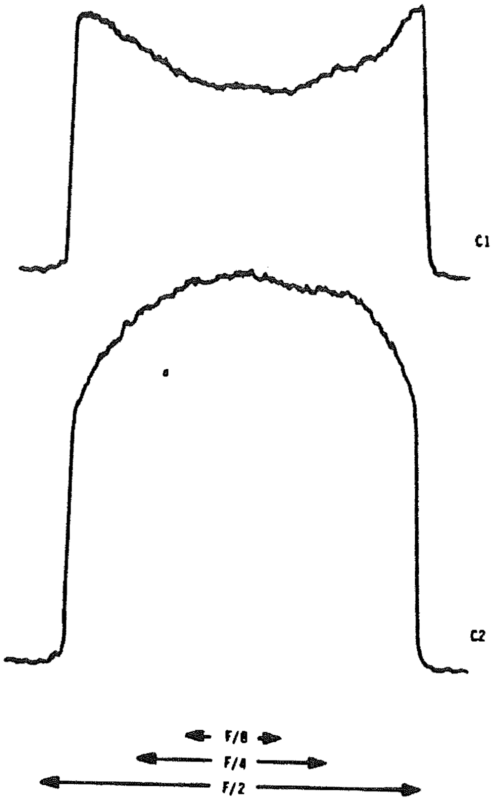

Figure 5. Exit pupil scans of two LEDs with ruby lenses.