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ULTIMATE BEAM EXPANSION RATIOS FOR ND: YAG LASER HARMONICS

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ABSTRACT
Beam expander plays a key role in laser devices for remote detection for transmission unit. The study is conducted for Nd: YAG laser wavelength 1064 nm and its harmonics, namely the second harmonic generation wavelength 532 nm, the third harmonic generation 355 nm, and the fourth harmonic generation 266 nm. Determination of expansion ratios of beam expander for specific wavelength and detection range is the key in beam expander optical design for determining minimum possible laser spot size at the target. Knowing ultimate expansion ratio implies to reduce laser transmitting unit dimensions and increase performance efficiency of receiving unit.

KEYWORDS: Laser, Beam Expander, Detection, Laser Spot.

INTRODUCTION
Beam expanders are useful laser accessories when the beam diameter must be increased. However, their main function is in decreasing the divergence of laser beams which are to be projected over long distances. Some laser field applications like range finder or laser lidar require a laser beam with low divergence angle. Reducing divergence angle requires expanding waist of laser beam (beam diameter) in question. This could be achieved by applying a beam expander. Generally, a beam expander consists of two lenses, and of two types: Galilean and Keplerian see figure (1). Firstly, the beam is diverged with a short focal length lens and secondly, the diverged beam is re-collimated with a longer focal length hence, larger beam waist and smaller divergence. The lenses are positioned like an inverted telescope [1].

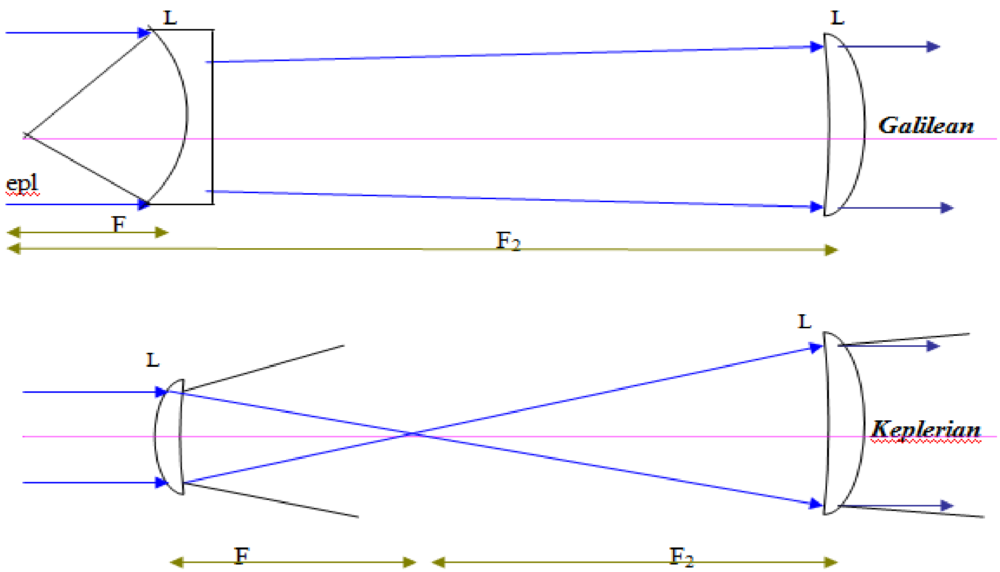

Figure (1) shows kinds of beam expander.

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ENERGETIC FORMULATION FOR TRANSMITTING LASER UNIT

Power flux, I_o, at laser source is given as [2]:

$$I_o = \frac{4P}{\pi wo^2} \quad \ldots\ldots (1)$$

Where P is transmitting peak power in Watt, which is given as:

$$P = \frac{E_o}{\tau_P} \quad \ldots\ldots (2)$$

Where E_o is energy of laser radiation in Joule.
τ_P is laser pulse width in nanosecond.
W_o is initial laser beam diameter in millimeter.

For a target at range R, diameter of laser beam at target's surface is:

$$W(r) = W_o \sqrt{1 + \left(\frac{\lambda R}{\pi W_o^2}\right)^2} \quad \ldots\ldots (3)$$

Where λ is laser radiation wavelength in nanometer.

Laser power flux at target's surface, I (R), is given as:

$$I(R) = \frac{P \tau_a \tau_{to}}{\Omega(t) R^2} \quad \ldots\ldots (4)$$

Where τ_a is atmospheric transmittance which is given as:

$$\tau_a = EXP(-\sigma_\lambda R) \quad \ldots\ldots (5)$$

where σ_λ is spectral coefficient of attenuation of laser radiation which is in Km^{-1}.

τ_{to} is transmittance of transmitting lenses.
Ω (t) is transmitting solid angle which is given in Stredian.

OPTICAL DESIGN CONSIDERATION

Applying beam expander to transmitting unit of laser in a question is useful in decreasing optical system elements dimensions. Choosing optimum expansion ratio for laser beam expansion could be achieved by determining minimum value for expansion ratio versus different ranges for specific wavelength [3].
Choosing minimum expansion ratio implies to:

[1] A smaller laser spot diameter is projected at range R,
[2] A higher intensity is reflected from the target in question,
[3] A smaller objective receiving unit diameter,
[4] A less detectivity for detection unit,
[5] Less expensive optical elements are applied due to smaller dimensions.

APPLYING BEAM EXPANDER TO TRANSMITTING UNIT

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As laser beam expander expansion ratio, ℵ increases:

- Objective lens of beam expander diameter increases.
- Laser beam divergence decreases, so that the spot diameter at the target will be decreased according to the following equation [4]:

$$W(R) = W_o \aleph \sqrt{1 + \left(\frac{\lambda R}{\pi \aleph^2 W_o^2}\right)^2} \quad \ldots\ldots (6)$$

- Laser spot intensity on target surface at R increases, so P(R) will be greater according to the following equation:

$$P(R) = \frac{4E_o \sigma_t A_c \tau_a^2 \tau_{to} \tau_{ro} \aleph}{\pi^2 \theta_f^2 \tau_P R^4} \quad \ldots\ldots (7)$$

Where θ_f is final divergence angle of laser beam

σ_t is scattering cross section.

τ_{ro} is transmittance of receiving unit

Hence receiving lens diameter, D_c, decreases; so that the area of receiving lens, A_c, will be decreased according to the following equation:

$$A_c = \frac{\pi^2 (S/N) NEP \theta_f^2 \tau_P R^4}{4E_o \sigma_t \tau_a^2 \tau_{to} \tau_{ro} \aleph} \quad \ldots\ldots (8)$$

Where S/N is signal to noise ratio.

NEP is noise equivalent power of the receiving unit detector.

EXPANSION RATIO VALUES FOR ND: YAG HARMONICS

Table (1) shows relationship between laser beam diameters versus different ranges for different wavelengths of Nd: YAG laser harmonics **without beam expander**, the initial laser beam diameter is 6 mm.

Table (1)

Wavelength (λ) (nm)	Range (R) (m)	Beam diameter (W_o) (Cm)
1064	5000	28.21
	10000	56.42
	15000	84.63
	20000	112.8
532	5000	14.11
	10000	28.21
	15000	42.32
	20000	56.42
355	5000	9.43
	10000	18.83
	15000	28.21
	20000	37.65
266	5000	7.07
	10000	14.11
	15000	21.16
	20000	28.21

The vital question is what is the ultimate limit at which expanding laser beam should be stopped? The answer of this question could be noticed in figures below which include Nd: YAG laser and its harmonics.

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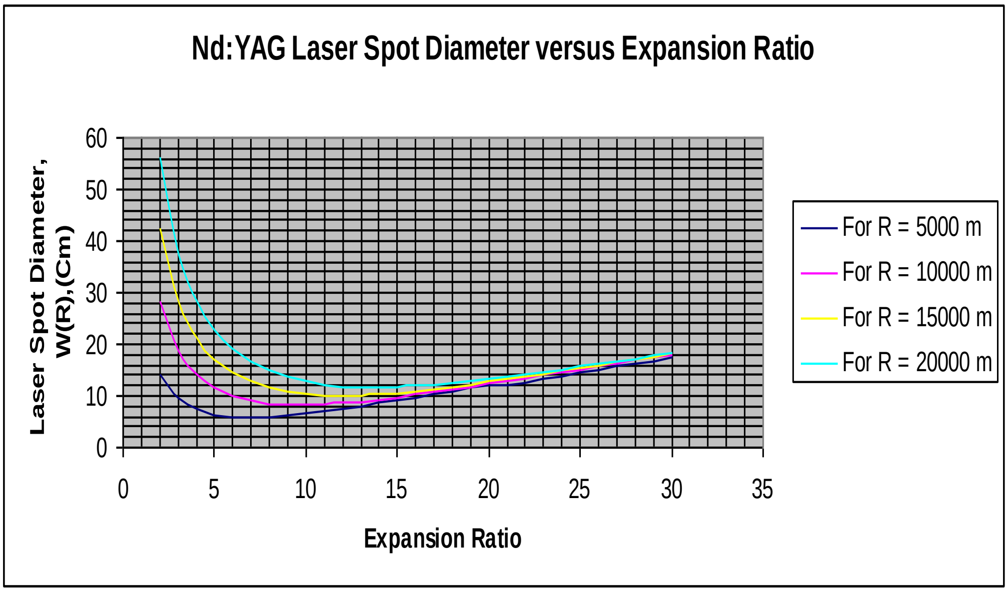

Figure (2) shows relationship between laser beam diameters versus different ranges for Nd: YAG laser wavelength, 1064 nm, with beam expander, the initial laser beam diameter is 6 mm.

Table (2) specifies values of each range for the above graph

Wavelength (λ) (nm)	Range (R) (m)	Optimum Expansion Ratio ($\aleph$)	Beam diameter W(R) (Cm)
1064	5000	6x	5.92
	10000	8x	8.27
	15000	10x	10.37
	20000	12x	11.84

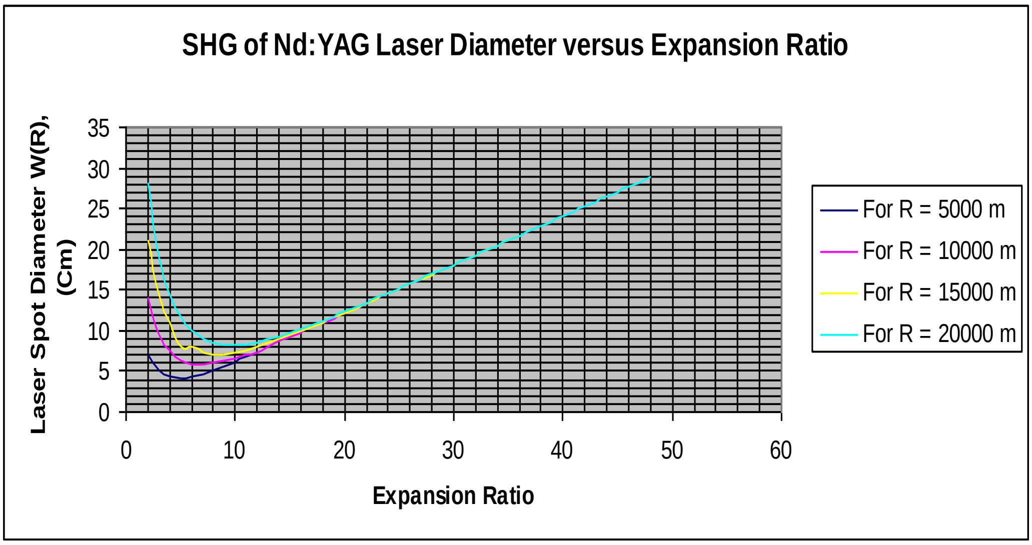

Figure (3) shows relationship between laser beam diameters versus different ranges for second harmonic generation of Nd: YAG laser wavelength, 532 nm, with beam expander, the initial laser beam diameter is 6 mm.

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Table (3) specifies values of each range for the above graph

Wavelength (λ) (nm)	Range (R) (m)	Optimum Expansion Ratio ($\aleph$)	Beam diameter W(R) (Cm)
532	5000	5x	4.26
	10000	6x	5.92
	15000	7x	7.36
	20000	8x	8.27

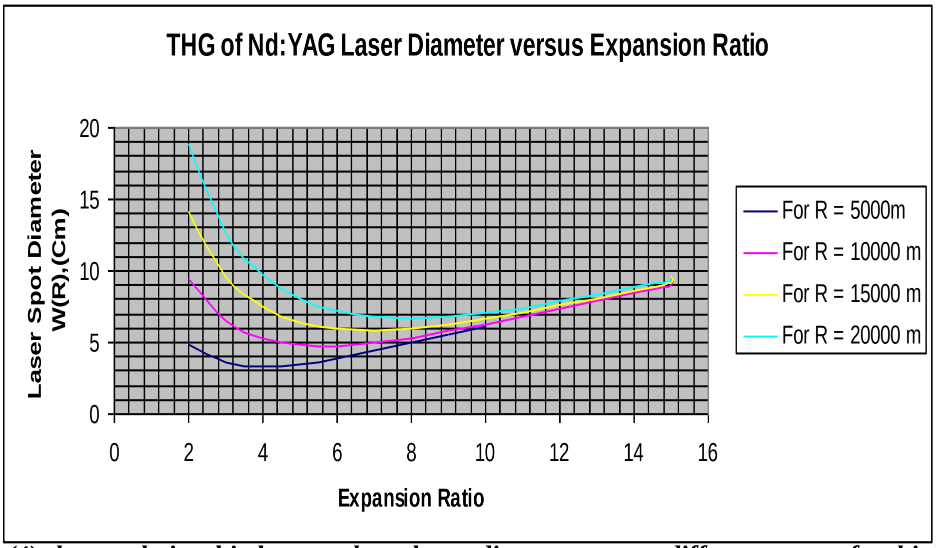

Figure (4) shows relationship between laser beam diameters versus different ranges for third harmonic generation of Nd: YAG laser wavelength, 355 nm, with beam expander, the initial laser beam diameter is 6 mm.

Table (4) specifies values of each range for the above graph

Wavelength (λ) (nm)	Range (R) (m)	Optimum Expansion Ratio ($\aleph$)	Beam diameter W(R) (Cm)
355	5000	4x	3.36
	10000	5x	4.81
	15000	6x	5.92
	20000	7x	6.82

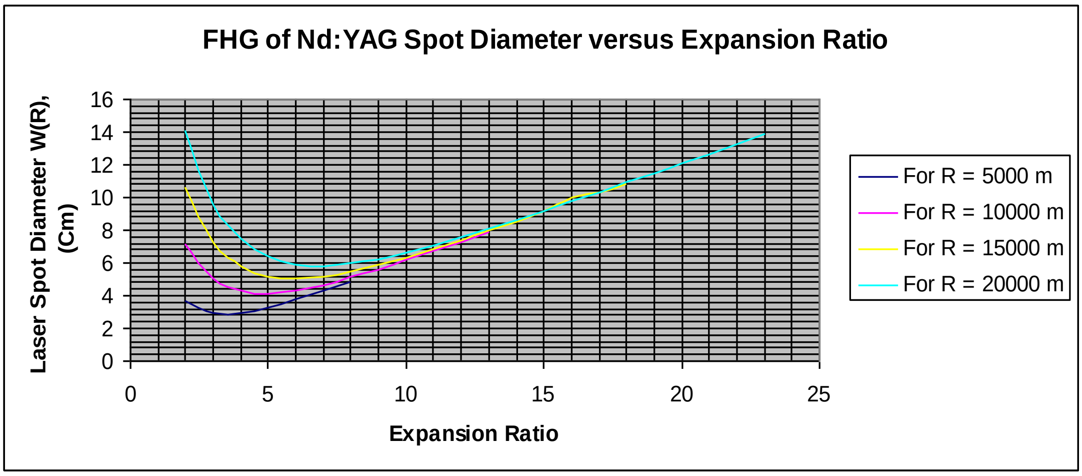

Figure (5) shows relationship between laser beam diameters versus different ranges for fourth harmonic generation of Nd: YAG laser wavelength, 266 nm, with beam expander, the initial laser beam diameter is 6 mm.

Table (5) specifies values of each range for the above graph

Wavelength (λ) (nm)	Range (R) (m)	Optimum Expansion Ratio ($\aleph$)	Beam diameter W(R) (Cm)
266	5000	3x	2.96
	10000	4x	4.26
	15000	5x	5.18
	20000	6x	5.92

CONCLUSION

Determination of expansion ratio for each wavelength of harmonics of Nd: YAG lasers play key role in designing accessories of transmitting unit namely; beam expander. As transmitting range increases for each wavelength, the expansion ratio increases too. Also as wavelength decreases, the expansion ratio decreases too comparing with the longer wavelength for specific range. So, according to the above mentioned data, beam expander size and weight will be reduced and its cost will be reduced too. In addition receiving unit dimensions, namely the receiving lens or mirror and detector will be decreased too.

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