Mansoura Engineering Journal

Volume 17 | Issue 3 Article 5

9-1-2021

Laser Beam Profile Shaping for Lidars with Diffraction Grating.

Ahmed Samra
Assistant Professor., Department of Electrical Communications., Faculty of Engineering .,El-Mansoura University., Mansoura., Egypt., shmed@mans.edu.eg

Recommended Citation

Samra, Ahmed (2021) "Laser Beam Profile Shaping for Lidars with Diffraction Grating.," *Mansoura Engineering Journal*: Vol. 17 : Iss. 3 , Article 5.
Available at: https://doi.org/10.21608/bfemu.2021.170451

Mansoura Engineering Journal (MEJ), Vol.17, No.3, Sept. 1992

LASER BEAM PROFILE SHAPING FOR LIDARS WITH DIFFRACTION GRATING

تشكيل شعاع الليزر للرادارات باستخدام محزيز الحيود

Ahmed S. Samra
Department of Electrical Communications
Faculty of Engineering - Mansoura University

الخلاصة: يستخدم هذا البحث تصميما لمشكل لشعاع الليزر ويقوم بتحويل مقطع شعاع الليزر ذى النمط الاساسى الى شكل ذى قمة مستوى عند المستوى البؤرى. ويستخدم المشكل محزوز الحيود ذا التبادل الايونى. وقد أختبرنا أداء المشكل وحصلنا على نتائج عملية تتفق مع التحليل النظرى.

ABSTRACT- A laser beam profile shaper was designed. It transforms a fundamental mode laser beam profile into flattop profile at a local plane. The shaper uses an ion-exchanged diffraction grating. The performance was tested and a good agreement between theoretical and experimental results was obtained.

I. INTRODUCTION

Laser radar, or Lidar (meaning light radar) as it is known, uses light as opposed to conventional microwaves. The most important advantage of using light in radar is that its extremely short wavelength permits intense scattering from micron-sized particles or the air molecules themselves. Therefore, lidar exhibits a high detection sensitivity for measuring minute particles or atmospheric constituents, although the visibility is limited in bad weather.

The principle of lidar is as follows: A pulsed laser beam is transmitted into the atmosphere, and the scattering signal is received by a telescope having an optical axis parallel to that of the beam. Information on the distribution of the scattering substances is obtained from echo patterns recorded (i.e the time history of the intensity of the scattered light is recorded by setting the time when the pulse is emitted as t = 0). To attain a good S/N ratio, powerful pulsed lasers are required. In conventional lidars, CO_2 lasers having a large pulse energy have been used as transmitter lasers.

Recent high resolution active infrared laser radar systems use detector arrays which reduce the scan rate and maintaing a wide field of view, but these arrays require **reshaping** of the transmitted laser beam profile to illuminate the far-field footprint of the array efficiently.

Laser beam shaping can be achieved in many ways: by reflection [1], refraction of beam fluxes [2], or by diffraction of energy [3]. Reflection and refraction techniques are energy efficient but generally require complicated aspheric surfaces, are sometimes nonrealizable, or do not preserve polarization.

Diffractive techniques can be energy efficient, simple, and flexible.

In the present paper, we propose a simple technique that uses an ion-exchanged diffraction transmission grating [4] to generate a far-field flattop profile from a centerosymmetric Gaussian beam.

II. BEAM SHAPING CONCEPT

The function of the beam shaper is to convert the incident laser beam amplitude profile (generally a fundamental mode Gaussian TEMoo) into a SINC(x) distribution to generate flattop distribution at the focal plane. In the same meaning, if an incident fundamental mode Gaussian beam amplitude with profile g(x) passing through the beam shaper (diffraction grating) with 1-D transmission function f(x), its far-field intensity distribution I(x") is a SINC(x) function and is determined by [3]

$$I(x') = | G(x'') \circledast F(x'') |^{2} \qquad (1)$$

where G(x") and F(x") are the Fourier transforms of g(x) and f(x), respectively, and $\circledast$ denoted the convolution operator. This is shown in Fig.1.

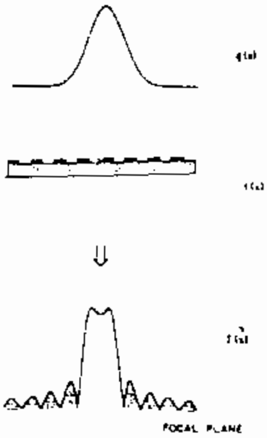

Fig.1 Concept of focal plane or far-field beam shaper

III. THEORETICAL STUDY

From the concept of the shaper, it is clear that, it must modulate the phase of the laser beam wave front in the near field so that the far-field distribution exhibits a flattop profile.

In this section, we shall discuss the possibility of using a diffraction grating fabricated by ion-exchange technique on glass substrate [4] to satisfy this requirement efficiently to the first order of diffraction.

Firstly, the transmittance of our 1-D diffraction grating can be described by

$$f(x) = 1/2 + 1/2 \cos(kx)$$
$$= 1/2 + 1/4 \left[\exp(jkx) + \exp(-jkx)\right] \qquad (2)$$

and is schematically indicated by Fig.2.

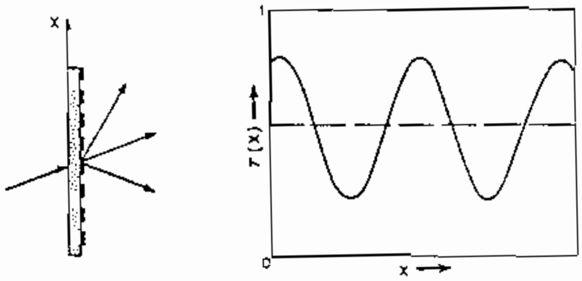

Fig.2 Schematic of transmission grating and the periodic variation of its transmission

In this function, the modulation phase depth of the grating is $kx = (2\, \Delta n_e / \lambda \cos\theta_i)x$, where Δn_e is the modulation of the effective index between the grating regions, λ is the laser beam wavelength, and we use for this study the He-Ne laser wavelength because it is the only one found in our laboratory and its value equal to 0.6328 μ m, and finally θ_i is the angle of incidence for the laser beam. In another publication [4], we have found that the optimum incident angle for maximum first order diffraction efficiency is the Bragg angle which is equal to $\sin^{-1}(\lambda / 2\, n_{e1}\, \Delta)$, where Δ is the grating periodicity and n_{e1} is the effective index of the guided wave mode.

Secondly, the 1-D fundamental mode Gaussian amplitude distribution can be described by [3]

$$g(x) = \exp\left[-\left(\frac{x^2}{\omega^2(z)} + \frac{j\pi x^2}{\lambda R(z)}\right)\right] \qquad (3)$$

where R(z) is the wavefront radius of curvature of the laserbeam and tends to ∞ at z = 0 but for any other value of z it is given by the following relation [5]

$$R(z) = z\left[1 + \left(\frac{\pi\,\omega^2(0)}{\lambda\, z}\right)^2\right] \qquad z \neq 0 \qquad (4)$$

where ω(0) is the initial beam radius of the Gaussian beam and at which the field amplitude is 1/e times that on the axis. Thus if a Gaussian beam initially has a beam radius ω(0) and plane wavefront at z = 0, as it propagates, its beam size increases to ω(z) and it develops a radius of curvature of the wavefront, R(z), as shown in Fig.3, where [5]

$$\omega(z) = \omega(0)\left[1 + \left(\frac{z\,\lambda}{\pi\,\omega^2(0)}\right)^2\right]^{1/2} \qquad (5)$$

For constant grating periodicity (10 μm) and various Laser beamwidth (by changing the position of the grating away from the laser exit aperture), the far-field intensity distributions under Gaussian plane wave illuminations for various σ's (σ = grating periodicity / (1/e beamwidth)) as expressed by Eq.(1) are plotted in Fig.4. It is found that the laser beam after passing through the diffraction grating shaper its far-field distribution has the required flattop profile, and also with decreasing σ, the profile edges become increasingly steeper relative to the previons profiles.

IV. EXPERIMENTAL RESULTS

We have studied shaped 0.6328-μm He-Ne Laser far-field beam profiles with ion-exchanged transmission grating. An avalanche photodetector recorded these profiles. The detector scanned stepwise through the beam profile by mounting it on an X-Y moving table graduated in micrometers. The detector is connected to a digital multimeter to read ont the results as shown in Fig.5.

In the far-field measurements the separation between shaper and detector was 1 meter.

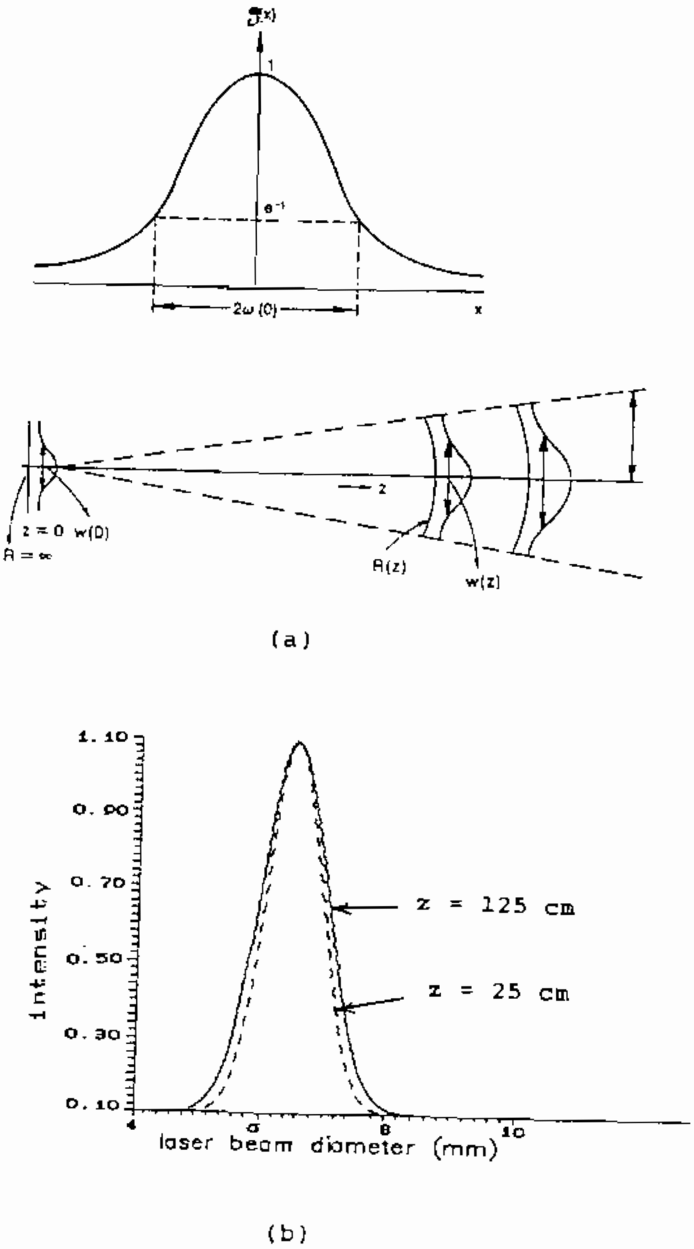

Fig.3 Propagation of Gaussian wavefront (a) principle and (b) evaluated at z = 25 cm and 125 cm for $\lambda = 0.6328\ \mu m$ of $\omega(0) = 0.612$ mm

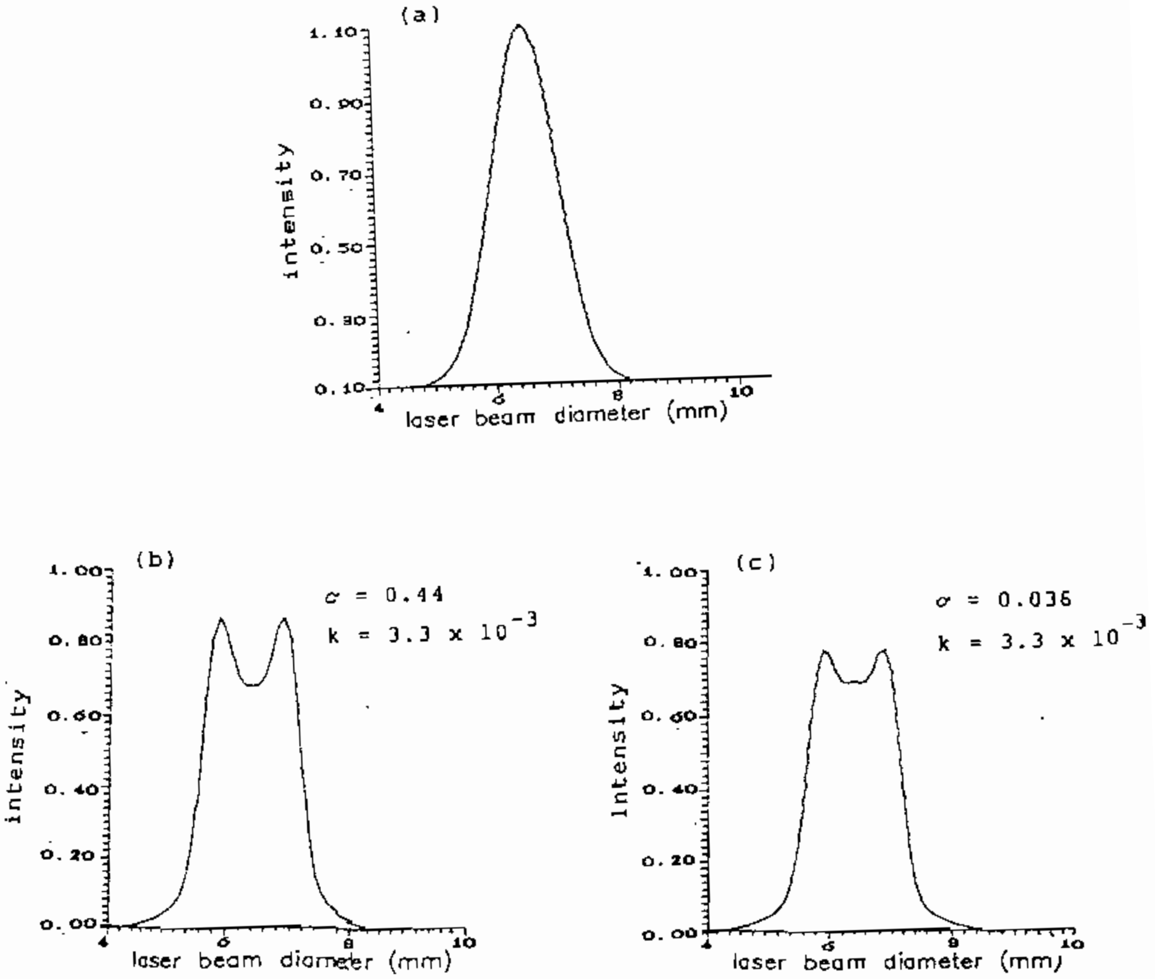

Fig.4 Far-field intensity distribution for various σ's
(a) unshaped laser beam
(b) shaped laser beam with σ = 0.036 and k = 3.3 x 10^{-3}
(c) shaped laser beam with σ = 0.044 and k = 3.3 x 10^{-3}

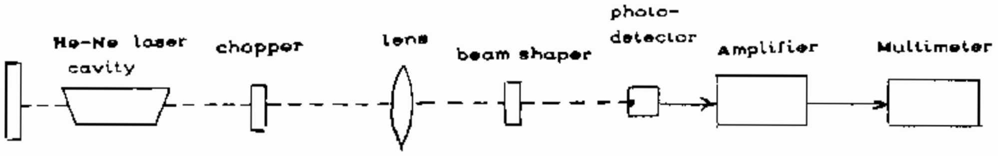

Fig.5 Experimental setup

Far-field test results of our shaper are shown in Fig.6, far-field profile (a) is the unshaped beam, profile (b) was generated by a shaper with σ of 0.44 at a location 20 cm away from the laser exit aperture and with $k = 3.3 \times 10^{-3}$, and profile (c) was generated with the same grating shaper but was made by sliding the shaper away from the laser to 25-cm location while maintaining the incident angle.

Therefore, with a fixed period grating the beam profile can be changed dynamically by sliding the shaper grating along the beam path.

V. CONCLUSION

We have presented an efficient flattop beam profile shaper. WE have shown how a Gaussian Laser beam profile can be converted to an approximate flattop distribution at the focal plane. The shaper we tested used an lon-exchanged diffraction transmission grating that modulated the phase of the incident beam. Many 714systems other than coherent laser radars, can benefit from the efficient conversion of a Gaussian profile into an expanded 1-D flattop profile.

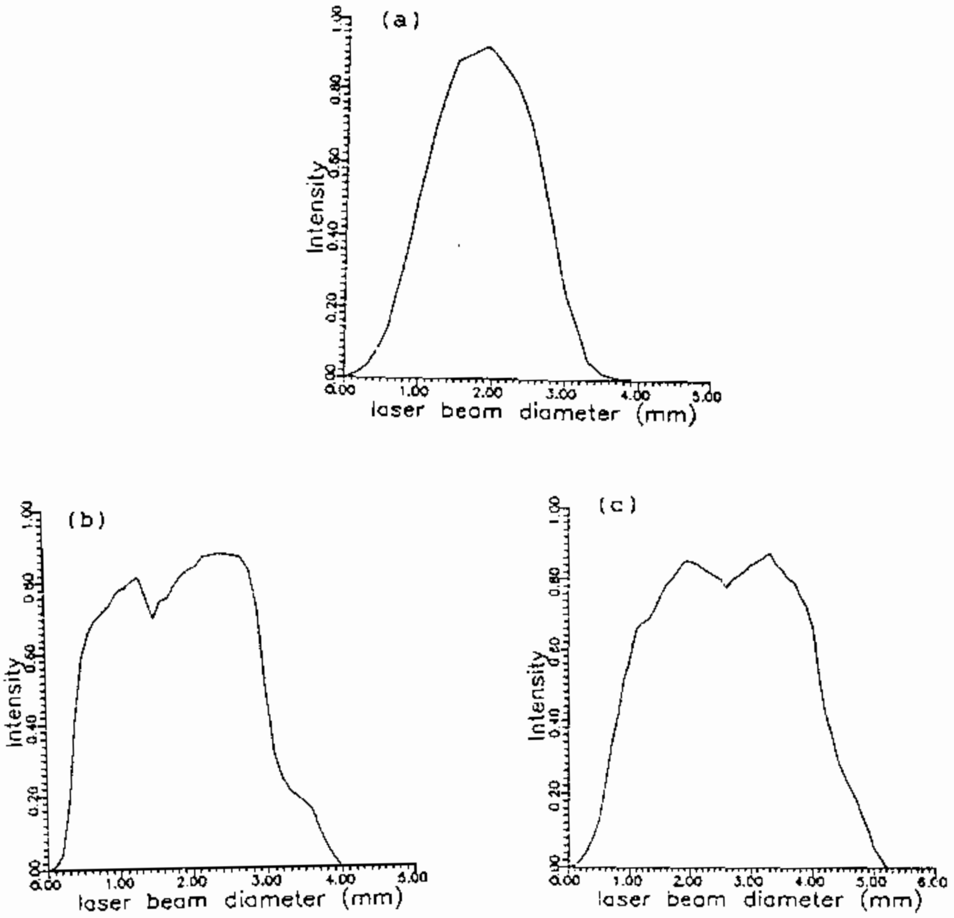

Fig.6 Scanned far-field intensity profile of He-Ne laser beam
(a) with no beam shaper
(b) with transmission mode beam shaper parameters
$\sigma = 0.036$, $k = 3.3 \times 10^{-3}$
(c) with $\sigma = 0.044$, $k = 3.3 \times 10^{-3}$

References

[1] J.W. Ogland, Appl. Opt. vol.17, no.18, p.2917 (1978) "Mirror system for uniform beam transformation in high-power annular lasers"

[2] P.W. Rhodes and D.L. Shealy, App. Opt. vol.19, no.20, p.3545 (1980). "Refraction optical systems for irradiance redistribution of collimated radiation: Their design and analysis"

[3] W.B. Veldkamp and Carol J. Kastner, Appl. Opt. vol.21, no.2, p.345 (1982). "Beam profile shaping for laser radars that use detector arrays".

[4] L. Gomaa, G.H. Chartier, and A.S. Samra, Journal of Physics D: Appl. Phys., no. 23, pp.1298-1301 (1990). "A novel technique for making demultiplexers in integrated optics".

[5] Pankaj K. Das, Optical signal processing, Springer-Verlag Berlin Heidelberg, (1991).