ARL-TR-8830 ● OCT 2019

A Zemax Analysis of a LIDAR Optical System to Compare Target Spot Size to Laser Input Angles and Beam Diameter

by Karl K Klett Jr, Barry Stann, and Bradley DeRoos

NOTICES

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REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED (From - To)
October 2019	Technical Report	1 Aug–20 Sep 2019

4. TITLE AND SUBTITLE	
A Zemax Analysis of a LIDAR Optical System to Compare Target Spot Size to Laser Input Angles and Beam Diameter	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
Karl K Klett Jr, Barry Stann, and Bradley DeRoos	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	**8. PERFORMING ORGANIZATION REPORT NUMBER**
CCDC Army Research Laboratory ATTN: FCDD-RLS-EE Adelphi, MD 20783-1138	ARL-TR-8830
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSOR/MONITOR'S ACRONYM(S)**
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This report describes the performance of optics that are part of a light imaging detection and ranging (LIDAR) system at the CCDC Army Research Laboratory. Part of the optics system consists of a tilt mirror that redirects a laser through lenses so the output location of the beam may be changed. The purpose of this analysis is to understand how the output angle changes with input angle, the dependence of the target spot size on the input angle, and how the laser beam diameter affects the target spot size. Using Zemax, a simulated laser was projected into the optical system at angles varying from 0° to 6°, and the output spot size varied from a 0.83-m circle at an input angle of 0° to a 13.2- × 3-m oval at an input angle of 6° using a 1-mm input beam. The output angles are a factor of five greater than the input angles.

15. SUBJECT TERMS

light imaging detection and ranging, LIDAR, Zemax, optics, tilt mirror, lasers

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Karl K Klett Jr
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (Include area code)
Unclassified	Unclassified	Unclassified	UU	16	(301) 394-0615

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

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1. Introduction

The light imaging detection and ranging (LIDAR) system is an active imaging system that provides range information. A laser is projected through an optical system to expand the beam and direct it to a target to be imaged. The purpose of this report is to understand how the spot size at the target varies with the input angle of the laser to the optics system. The change of the output angle, after the laser passes through the lenses, compared with the input angle is also calculated. Figure 1 shows the LIDAR optical system described in this report. The laser source is a 1550-nm laser. The tilt mirror's tilt axis is perpendicular to the plane of the figure and moves 6° to each side of the on-axis projection of the laser through the lens system. The first lens, nearest to the tilt mirror, is a 25-mm focal length, 12.7-mm-diameter cemented acromatic doublet (AC/127-025-C) made by Thor Labs (Newton, New Jersey). The second lens is a 9.7-mm focal length, 12.7-mm-diameter double-concave lens (SLB-12.7B-10NIR2/W3060) made by OptoSigma (Santa Ana, California).

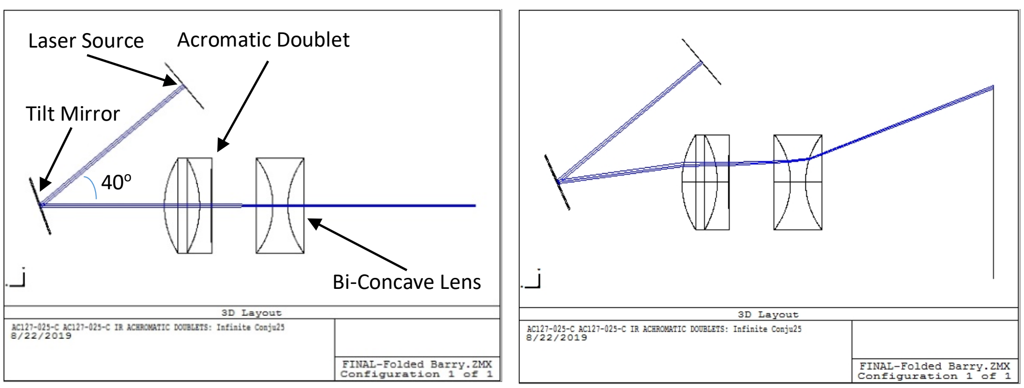


Fig. 1 LIDAR optical system showing on-axis projection (0° tilt) of a 1-mm-diameter laser (left) and 4° tilt (right)

2. Methods, Assumptions, Procedures

Zemax-EE (32-bit), Version Sep 17, 2010, was used to model the optical system. The Zemax lens data editor (LDE), shown in Fig. 2, shows the design of the optical system. A 1-mm aperture stop (Line 2 of the LDE) produces the Gaussian laser profile. The laser has a 1-milliradian divergence, which was entered into the Field Data (Zemax 2011, p. 51). Line 4 of the LDE places the tilt mirror in the proper location.

Lens Data Editor

Edit Solves View Help

	Surf:Type	Comment	Radius	Thickness	Glass	Semi-Diameter	Conic	Par 0 (unused)	Par 1 (unused)	Par 2 (unused)	Par 3 (unused)	Par 4 (unused)	Par 5 (unused)	Par 6 (unused)	Par 7 (unused)
OBJ	Standard		Infinity	Infinity		0.000	0.000								
1	Standard	STOP	Infinity	25.000		4.000 U	0.000								
2	Coordinat..			0.000	-	0.000			0.000	0.000	-20.000	0.000	0.000	0	
3	Coordinat..	Element Tilt		0.000	-	0.000			0.000	0.000	4.000	0.000	0.000	0	
4*	Standard	STOP-MIRROR	Infinity	0.000	MIRROR	4.000 U	0.000								
5	Coordinat..	Element Tilt		0.000	-	0.000			0.000 P	0.000 P	-4.000 P	0.000 P	0.000 P	1	
6	Coordinat..			-16.510	-	0.000			0.000	0.000	-20.000 P	0.000	0.000	0	
*	Standard	Sur 1 Plano-Cvx	-12.000	-4.700	N-LAK22	6.350 U	0.000								
8*	Standard	Sur 2 Plano-Cvx	12.940	-1.500	N-SF6HT	6.350 U	0.000								
9*	Standard	Sur 3 Plano-Cvx	-151.710	-8.256		6.350 U	0.000								
10*	Standard	Suf 1 Bi-Ccv	10.380	-2.000	BK7	6.350 U	0.000								
11*	Standard	Sur 2 Bi-Ccv	-10.380	-25.000		6.350 U	0.000								
IMA	Standard		Infinity	-		12.879	0.000								

Fig. 2 Zemax LDE showing entries graphically depicted in Fig. 1

To implement the tilt mirror oriented at 40° to the optical axis, two coordinate breaks are needed. These are shown in Lines 2 and 6 of the LDE. The first coordinate break, shown in Line 2, rotates the coordinate system 20° to initiate the fold. The fold mirror is normal to this new coordinate system. The second coordinate break, shown in Line 6 of the LDE, rotates the axis another 20° to complete the fold and follow the reflected beam. Lines 3 and 5 of the LDE are two coordinate breaks that are then required to tilt the mirror 6° on either side of the optical axis (Geary 2002, p. 423). This tilt is adjusted by entering values from 0° to 6° in Line 3, Par3 column of the LDE. Figure 2 shows the tilt angle set at 4° off the optical axis.

The parameters of the Thor Labs cemented acromatic doublet were available online in a Zemax format, and that information was copied directly into the Zemax LDE in Lines 7–9 (Locke 2006). The radius of curvature of the OptoSigma double-concave lens (10.38 mm) was available online and was manually entered into the LDE in Lines 10–11.

The distance to the target (Line 11, thickness) was evaluated at 150 m along with the laser profiles, which were analyzed at a diameter of 1 and 3 mm. The laser profiles at the target were evaluated at tilt mirror angles of 0°, 2°, 3°, 4°, and 6° from an on-axis projection.

3. Results and Discussion

The tilt mirror was changed from 0° to 6° from the on-axis location of the initial 40° placement of the mirror. At each angle, the spot diagram was evaluated to measure the spot size and determine the output angle.

3.1 Variation of Output Angle and Target Spot Size with Input Angle

Tables 1 and 2 are a quantitative analysis of LIDAR operating scenarios (shown in Fig. 1) and show the results for 1- and 3-mm-diameter laser inputs to the optical system, respectively. In these analyses, the target is at 150 m.

Table 1 LIDAR input/output parameters for a 1-mm input beam

Beam size (mm)	Input angle (deg)	Distance to target (m)	Vertical offset at target (m)	Vertical offset / Distance to target	Output angle (deg)	Spot size diameter or major/minor axis at 150 m (size in m)
1	0	150	0	0	0	0.830 (circle)
1	2	150	26.278	0.1752	9.93	1.04 × 0.9 (oval)
1	3	150	40.952	0.273	15.26	1.36 × 1.06 (oval)
1	4	150	58.162	0.3877	21.19	2.08 × 1.28 (oval)
1	6	150	120.665	0.8044	38.81	13.2 × 3.0 (oval)

Table 2 LIDAR input/output parameters for a 3-mm input beam

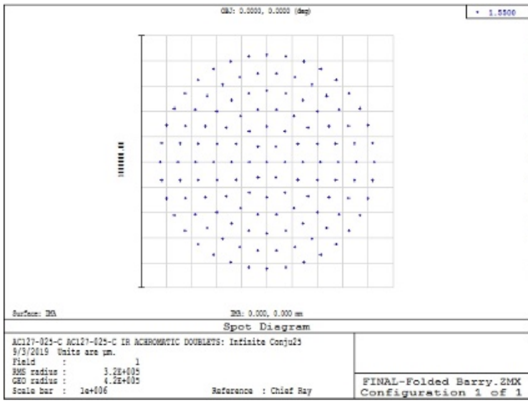
Beam size (mm)	Input angle (deg)	Distance to target (m)	Vertical offset (m)	Vertical offset / Distance to target	Output angle (deg)	Spot size diameter or major/minor axis at 150 m (size in m)
3	0	150	0	0	0	2.6 (circle)
3	2	150	26.278	0.1752	9.93	3.2 × 2.88 (oval)
3	3	150	40.952	0.273	15.26	4.2 × 3.3 (oval)
3	4	150	58.162	0.3877	21.19	6.7 × 4.0 (oval)
3	6	150	120.665	0.8044	38.81	59.0 × 11.0 (oval)

Five input angles are analyzed from 0° to 6°. Input/output angles are identical for the 1- and 3-mm beams in Tables 1 and 2. An input angle of 0° corresponds to the laser being projected on-axis, through the center of the lenses, and an input angle of 6° is the largest input angle where the rays of the laser are contained within the optics used in the system. The angle of the output rays from the optical system of the LIDAR are greater than the angle of the input rays. The ratio between the output angle and the input angle is about 5, but the ratio of the 6° input ray is approximately 6.5. This deviation is not surprising since the rays are very close to the edge of the lens, where there are major aberrations of the optics.

There is an increase in spot size for both beam diameters (1 and 3 mm) as the input angle of the laser increases. In these analyses, the laser diameter and input angle have a large impact on spot size. The 1-mm-diameter laser spot size, at a target distance of 150 m, varies from a 2.16 m^2 circle at a 0° input angle to a 124.4 m^2 oval at a 6° input angle. The 3-mm-diameter laser spot size, at a target distance of 150 m varies from a 21.23 m^2 circle at a 0° input angle to a 2038.89 m^2 oval at a 6° input angle. Spot size at the target is dependent not only on input angle, but also on the laser diameter.

3.2 Target Spot Size Figures

Figures 3 and 4 show the size and shape of the laser spot pattern at the target, projected through the optics of the LIDAR system described in this report, at 150 m. The scale of these figures vary so the shape of the spot can be easily seen.



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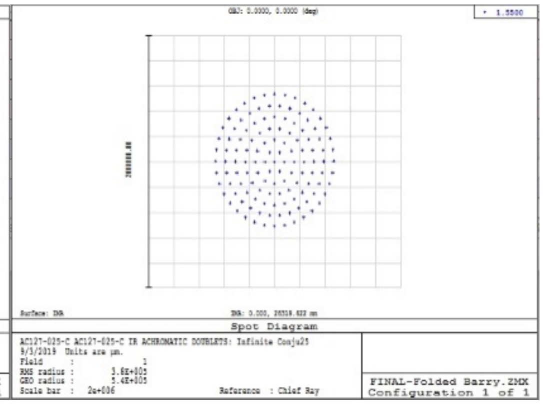

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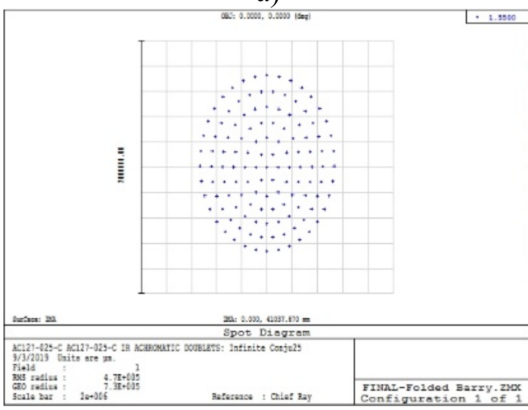

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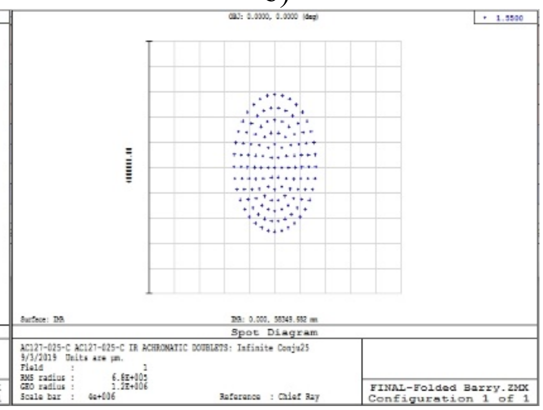

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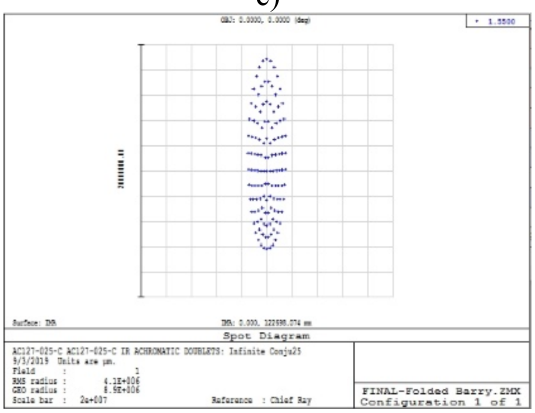
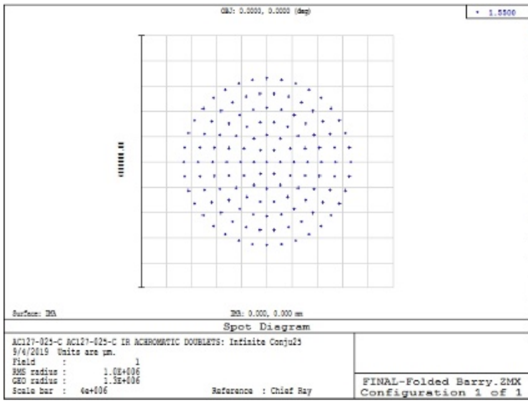


e)

Fig. 3 Spot diagrams for a 1-mm-diameter parabolic LIDAR laser projected through the optics analyzed in this report. The laser is input into the optics system at a) 0°, b) 2°, c) 3°, d) 4°, and e) 6°. Note: the scale varies from figure to figure.



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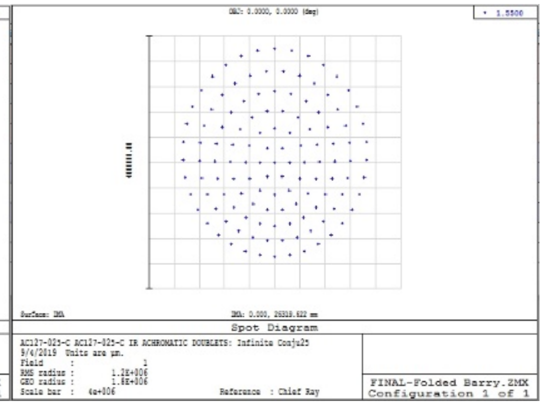

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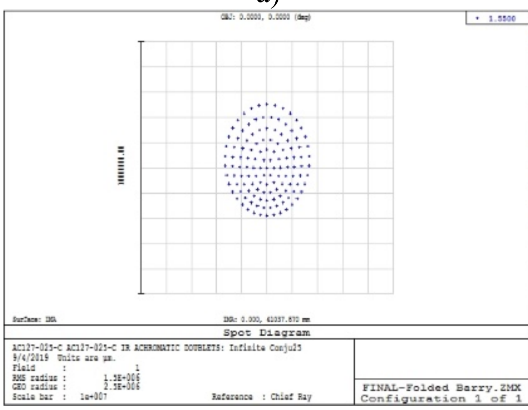

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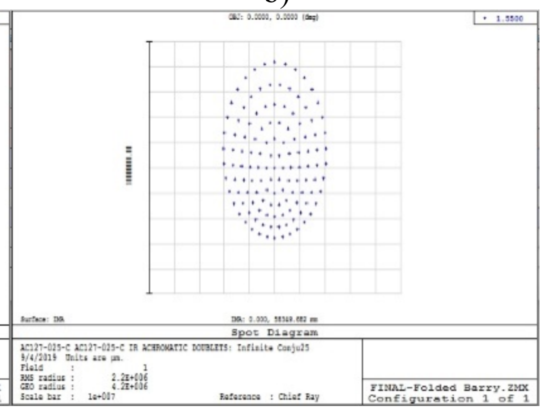

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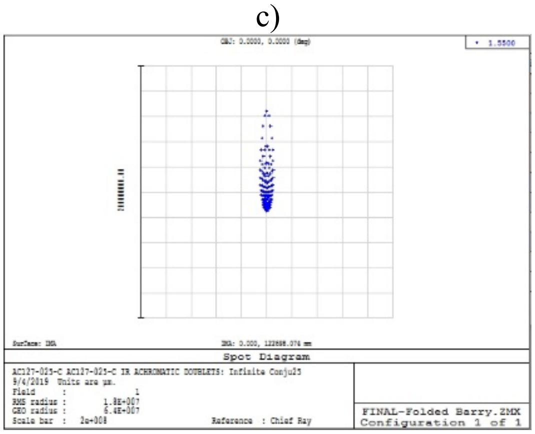

e)

Fig. 4 Spot diagrams for a 3-mm-diameter parabolic LIDAR laser projected through the optics analyzed in this report. The laser is input into the optics system at a) 0°, b) 2°, c) 3°, d) 4°, and e) 6°. Note: the scale varies from figure to figure.

4. Conclusion

This analysis considered the effects of laser diameter and input angle to evaluate their effects on the spot size of the laser on the target. The input angle was also compared with the output angle after the laser passed through the optical system.

Beam diameter plays a significant role in increasing the size of the laser spot at the target. A 3-mm-diameter on-axis laser increase in size by a factor of approximately 50 compared with a 1-mm-diameter beam. A 3-mm-diameter beam, projected into the optics system at 6°, is larger by a factor of approximately 100, compared with a 1-mm beam.

Beam angle also plays a significant role in increasing the size of the laser spot at the target. A 1-mm beam, varied from an input angle of 0° to 6°, increases in size by about a factor of 57. A 3-mm beam, varied from an input angle of 0° to 6°, increases in size by about a factor of 96.

For both sizes of beams, the output angle was larger, by a factor of approximately five, compared with the input angle of the laser.

Hopefully, these analyses will help researchers develop LIDAR systems that are more effective and useful for the US military and others in government.

5. References

Geary JM. Introduction to lens design: with practical Zemax examples. Richmond (VA): Willmann-Bell, Inc; 2002.

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[Zemax] Zemax optical design program user's manual. Kirkland (WA): Zemax LLC. 2011 Jul 8. [accessed 2019 Sep 20] https://neurophysics.ucsd.edu/Manuals/Zemax/ZemaxManual.pdf.

List of Symbols, Abbreviations, and Acronyms

LDE	lens data editor
LIDAR	light imaging detection and ranging

1 (PDF)	DEFENSE TECHNICAL INFORMATION CTR DTIC OCA
1 (PDF)	CCDC ARL FCDD RLD CL TECH LIB
1 (PDF)	GOVT PRINTG OFC A MALHOTRA
2 (PDF)	CCDC ARL FCDD RLS EE K KLETT B STANN