Beam Shaper

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1 Keplerian Type Beam Shaper

Simulation with parameters and lens data sheet given in *Laser Beam Shaping Techniques*

$$\omega_0 = 2.366 \quad R_{max} = 4.05 \quad r_{max} = 4.05 \quad n = 1.46071 \quad d = 150 \tag{1}$$

The parameters gives the apodization factor as:

$$G = \left(\frac{r_{max}}{\omega_0}\right)^2 \approx 2.93 \tag{2}$$

The key settings of all the Geometric Image Analysis in Zemax OpticStudio are as below:

$$\text{Image Size} = 10 \quad \text{Rays x 1000} = 500000 \quad \#\ \text{Pixels} = 200 \quad \text{Total Watts} = 1 \tag{3}$$

1.1 Initial system

The lens data sheet given in *Laser Beam Shaping Techniques*:

TABLE 7.1
Design Data for Plano-Aspheric Lens Pair of Keplerian Beam Shaper Calculated Based on the Third-Order Aberration Theory

No.	r_c	t_c	Glass	k	n_{532}
		Infinity			1
1	Infinity	3	Fused silica		1.46071
2	−20.182	150		−48.71	1
3	48.925	3	Fused silica	17.08	1.46071
4	Infinity				1

Figure 1: Initial Keplerian type beam shaper system.

This system gives a profile as below in Zemax OpticStudio:

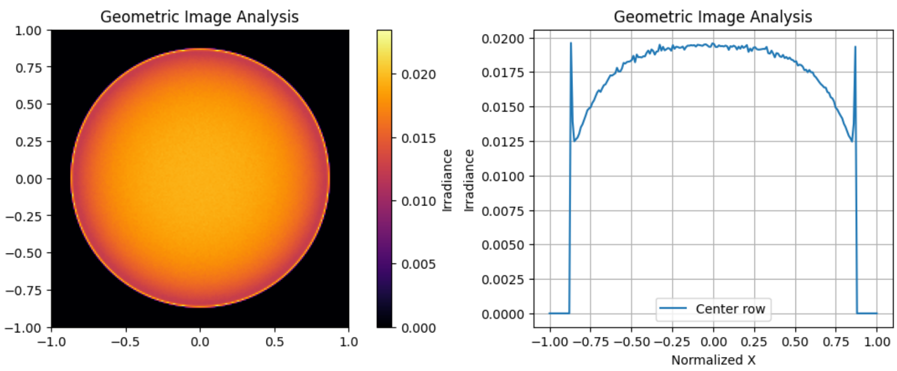

Figure 2: Initial beam profile at the output plane.

1.2 Optimized with only conic constants

The lens data sheet given in *Laser Beam Shaping Techniques*:

TABLE 7.2
Design Data for Plano-Aspheric Lens Pair of Keplerian Beam Shaper with the Second-Order Aspheric Surfaces Whose Parameters Are Corrected by Optimization Method

No.	r_c	t_c	Glass	k	n_{532}
		Infinity			1
1	Infinity	3	Fused silica		1.46071
2	−20.182	150		−54.8	1
3	48.925	3	Fused silica	29.5	1.46071
4	Infinity				1

Figure 3: Optimized Keplerian type beam shaper system with only conic constant as variable.

In Zemax OpticStudio, the output profile given by this is:

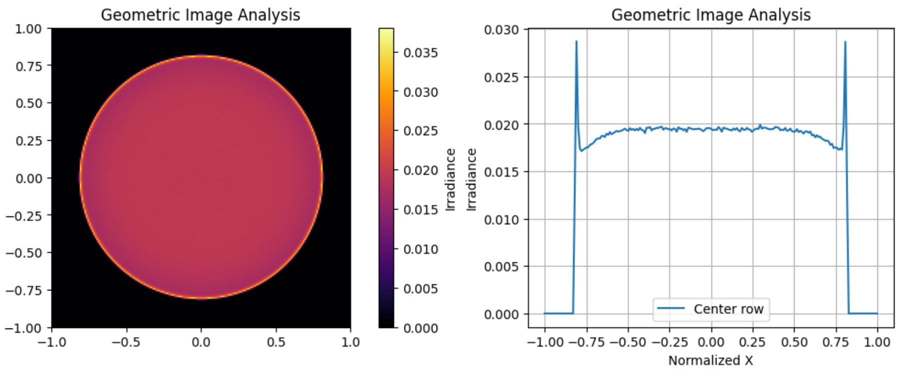

Figure 4: Output beam profile at the output plane after optimization with only conic constant as variable.

1.3 Optimized with up to 4th order of the second aspheric

The lens data sheet given in *Laser Beam Shaping Techniques*:

TABLE 7.3
Design Data for Plano-Aspheric Lens Pair of Keplerian Beam Shaper Where First Aspheric Has the Second-Order and the Second Aspheric Has the Fourth Order

No.	r_c	t_c	Glass	Asphere Coefficients	n_{532}
		Infinity			1
1	Infinity	3	Fused silica		1.46071
2	−20.1	150		$k = -55.62$	1
				$A_4 = -6.27 \times 10^{-5}$	
3	48.75	3	Fused silica	$K = 67.22$	1.46071
4	Infinity				1

Figure 5: Optimized Keplerian type beam shaper system with up to 4th order as variable.

In Zemax OpticStudio, the output profile given by this is:

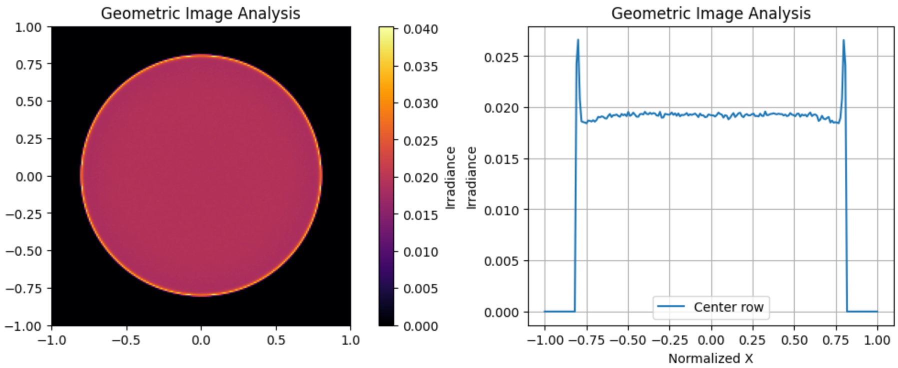

Figure 6: Output beam profile at the output plane after optimization with up to 4th order as variable.

1.4 Optimized with up to 6th order of the second aspheric

The lens data sheet given in *Laser Beam Shaping Techniques*:

TABLE 7.4
Design Data for Plano-Aspheric Lens Pair of Keplerian Beam Shaper When the First Aspheric Has the Second Order and the Second Aspheric Has the Sixth Order

No.	r_c	t_c	Glass	Asphere Coefficients	n_{532}
		Infinity			1
1	Infinity	3	Fused silica		1.46071
2	−20.1	150		$k = -55.6$ $A_4 = -6.27 \times 10^{-5}$ $A_6 = -2.06 \times 10^{-6}$	1
3	49.11	3	Fused silica	$k = 86.42$	1.46071
4	Infinity				1

Figure 7: Optimized Keplerian type beam shaper system with up to 6th order as variable.

In Zemax OpticStudio, the output profile given by this is:

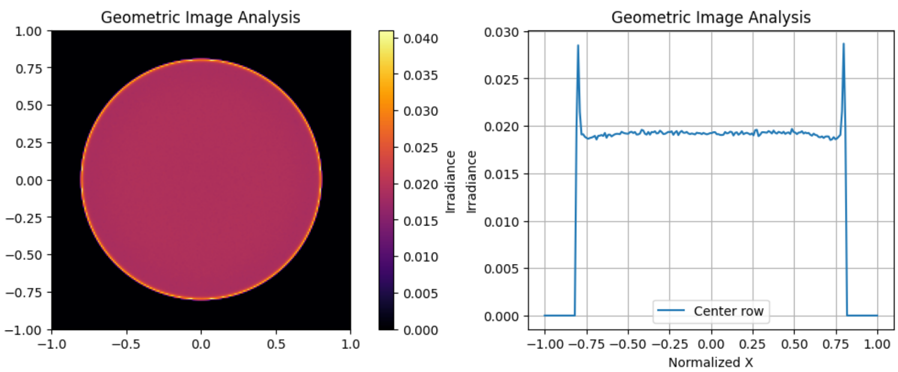

Figure 8: Output beam profile at the output plane after optimization with up to 6th order as variable.

2 Galilean Type Beam Shaper

Since the Galilean type beam shaper can not result in a 1:1 beam size conversion, for making a better comparison, the R_max is timed by 3 to make the marginal ray get bent the same size of angle with respect to the optical axis but in an opposite direction.

So the parameters are modified as below:

$$\omega_0 = 2.366 \quad R_{max} = 12.15 \quad r_{max} = 4.05 \quad n = 1.46071 \quad d = 150 \tag{4}$$

The key settings of all the Geometric Image Analysis in Zemax OpticStudio are as below:

$$\text{Image Size} = 32 \quad \text{Rays x 1000} = 500000 \quad \#\ \text{Pixels} = 200 \quad \text{Total Watts} = 1 \tag{5}$$

2.1 Initial system

Given the parameters above, the initial system's lens data can be derived using equations provided in *Laser Beam Shaping Techniques* (for the calculations, please refer to the `beam_shaper.py` file):

		Surface Type	Comme	Radius	Thickness	Material	Co:	Clear Semi	Chip Zo	Mech Ser	Conic
0	OBJECT	Standard		Infinity	Infinity			0.000	0.000	0.000	0.000
1		Standard	Dummy	Infinity	10.000			4.050	0.000	4.050	0.000
2	STOP	Standard		Infinity	3.000	1.46,0.0 M		4.050	0.000	4.050	0.000
3		Standard		11.017	150.000			4.050	0.000	4.050	-30.693
4		Standard		Infinity	0.000			15.466	0.000	15.466	0.000
5		Standard		80.124	3.000	1.46,0.0 M		15.577	0.000	15.577	-6.061
6		Standard		Infinity	10.000			15.570	0.000	15.577	0.000
7	IMAGE	Standard		Infinity	-			15.506	0.000	15.506	0.000

Figure 9: Initial Galilean type beam shaper system.

The output beam profile is:

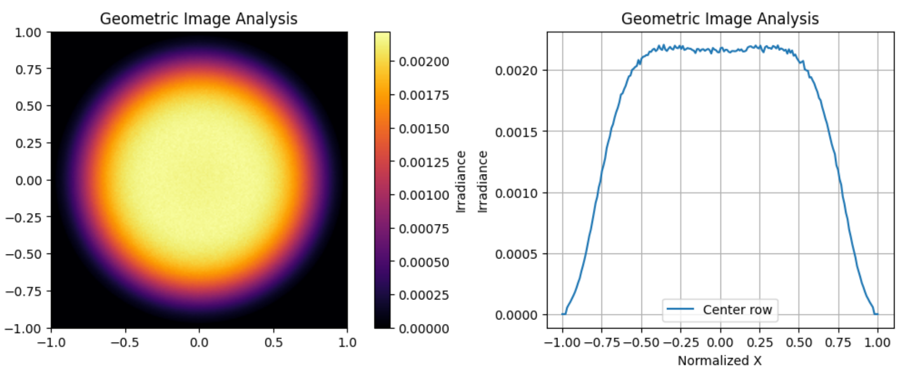

Figure 10: Output beam profile at the output plane for the initial Galilean type beam shaper system.

2.2 Optimized with only conic constants

According to the ray mapping function for Galilean type given in *Laser Beam Shaping Techniques*:

$$R = R_{max} \sqrt{\frac{1 - \exp[-2(r/\omega_0)^2]}{1 - \exp[-2(r_{max}/\omega_0)^2]}} \tag{6}$$

The merit function can be written in Python (please refer to `ZOS_Galilean_Beam_Shaper.ipynb` for details).

After optimization with only conic constant as variable, the lens data is:

	Surface Type		Comment	Radius		Thickness	Material	Coating	Clear Semi-Dia	Chip Zone	Mech Semi-Dia	Conic	
0	OBJECT	Standard		Infinity		Infinity			0.000	0.000	0.000	0.000	
1		Standard	Dummy	Infinity		10.000			4.050	0.000	4.050	0.000	
2	STOP	Standard		Infinity		3.000	1.46,0.0 M		4.050	0.000	4.050	0.000	
3		Standard		11.055	V	150.000			4.050	0.000	4.050	-37.184	V
4		Standard		Infinity		0.000			14.563	0.000	14.563	0.000	
5		Standard		80.162	V	3.000	1.46,0.0 M		14.611	0.000	14.676	-228.823	V
6		Standard		Infinity		10.000			14.676	0.000	14.676	0.000	
7	IMAGE	Standard		Infinity		-			15.090	0.000	15.090	0.000	

Figure 11: Optimized Galilean type beam shaper system with only conic constant as variable.

Which gives a slightly better output beam profile:

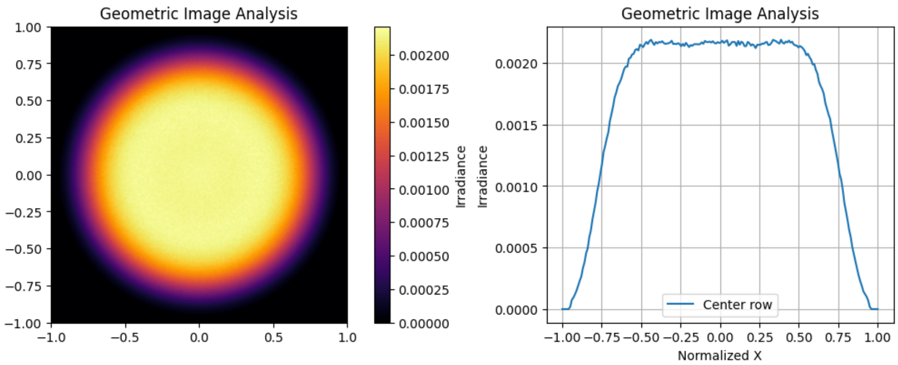

Figure 12: Output beam profile at the output plane after optimization with only conic constant as variable.

2.3 Optimization focusing on the second aspheric

2.3.1 Optimized with up to 4th order of the second aspheric

After optimization with up to 4th order as variable, the lens data is:

	Surface Type		Comme	Radius		Thickness	Material	Co	Clear Semi	Chip Zo	Mech Ser	Conic		TCE x 1E-6	2nd Order Term	4th Order Term	
0	OB.	Standard		Infini...		Infinity			0.000	0.000	0.000	0.000		0.000			
1		Standard	Dummy	Infini...		10.000			4.050	0.000	4.050	0.000		0.000			
2	STC	Standard		Infini...		3.000	1.46,0.0 M		4.050	0.000	4.050	0.000		0.000			
3		Standard		11.120	V	150.000			4.050	0.000	4.050	-33.987	V	0.000			
4		Standard		Infini...		0.000			14.965	0.000	14.965	0.000		0.000			
5		Even Asphere		80.227	V	3.000	1.46,0.0 M		15.057	0.000	15.057	-440.493	V	0.000	0.000	1.389E-05	V
6		Standard		Infini...		10.000			15.014	0.000	15.057	0.000		0.000			
7	IM/	Standard		Infini...		-			14.650	0.000	14.650	0.000		0.000			

Figure 13: Optimized Galilean type beam shaper system with up to 4th order as variable.

Which gives an output beam profile with wider flat top region:

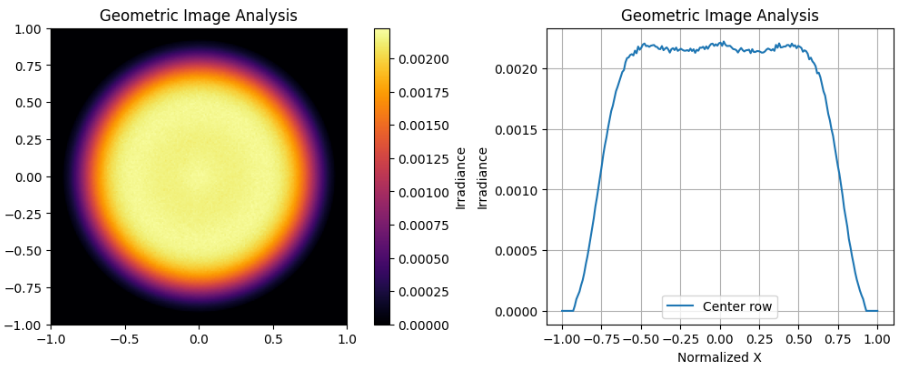

Figure 14: Output beam profile at the output plane after optimization with up to 4th order as variable.

2.3.2 Optimized with up to 6th order of the second aspheric

After optimization with up to 6th order as variable, the lens data is:

	Surface Type		Comment	Radius		Thickness	Material	Coating	Clear Semi-Dia	Chip Zone	Mech Semi-Dia	Conic		TCE x 1E-6	2nd Orde	4th Order Ter		6th Order Term	
0	OBJECT	Standard		Infini...		Infinity			0.000	0.000	0.000	0.000		0.000					
1		Standard	Dummy	Infini...		10.000			4.050	0.000	4.050	0.000		0.000					
2	STOP	Standard		Infini...		3.000	1.46,0.0 M		4.050	0.000	4.050	0.000		0.000					
3		Standard		11.090	V	150.000			4.050	0.000	4.050	-43.715	V	0.000					
4		Standard		Infini...		0.000			13.842	0.000	13.842	0.000		0.000					
5		Even Asphere		80.197	V	3.000	1.46,0.0 M		13.888	0.000	13.888	-11.207	V	0.000	0.000	-6.976E-05	V	3.036E-07	V
6		Standard		Infini...		10.000			13.741	0.000	13.888	0.000		0.000					
7	IMAGE	Standard		Infini...		-			12.803	0.000	12.803	0.000		0.000					

Figure 15: Optimized Galilean type beam shaper system with up to 6th order as variable.

Which gives an output beam profile with even wider flat top region:

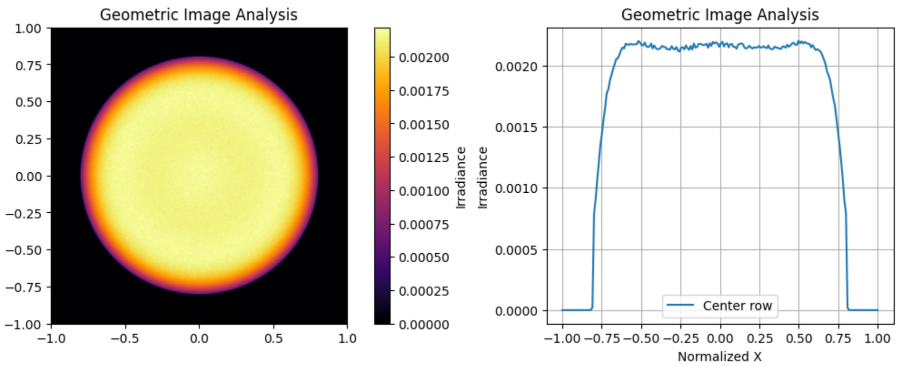

Figure 16: Output beam profile at the output plane after optimization with up to 6th order as variable.

2.4 Optimization focusing on the first aspheric

Optimization focusing on the second aspheric behaves not well enough, so the first aspheric is optimized instead.

2.4.1 Optimized with up to 4th order of the first aspheric

After optimization with up to 4th order as variable, the lens data is:

		Surface Type	Comment	Radius	Thickness	Material	Coating	Clear Semi-Dia	Chip Zone	Mech Semi-Dia	Conic	TCE x 1E-6	Par 1(unused)	Par 2(unused)
1		Standard	Dummy	Infinity	10.000			4.050	0.000	4.050	0.000	0.000		
2	STOP	Standard		Infinity	3.000	1.46,0.0 M		4.050	0.000	4.050	0.000	0.000		
3		Even Asphere		10.970 V	150.000			4.050	0.000	4.050	-23.856 V	0.000	0.000	-2.663E-04 V
4		Standard		Infinity	0.000			11.748	0.000	11.748	0.000	0.000		
5		Standard		80.076 V	3.000	1.46,0.0 M		11.803	0.000	11.803	27.254 V	0.000		
6		Standard		Infinity	10.000			11.727	0.000	11.803	0.000	0.000		
7	IMAGE	Standard		Infinity	-			11.146	0.000	11.146	0.000	0.000		

Figure 17: Optimized Galilean type beam shaper system with up to 4th order of the first aspheric as variable.

Which gives an output beam profile with a much wider and flatter flat top region:

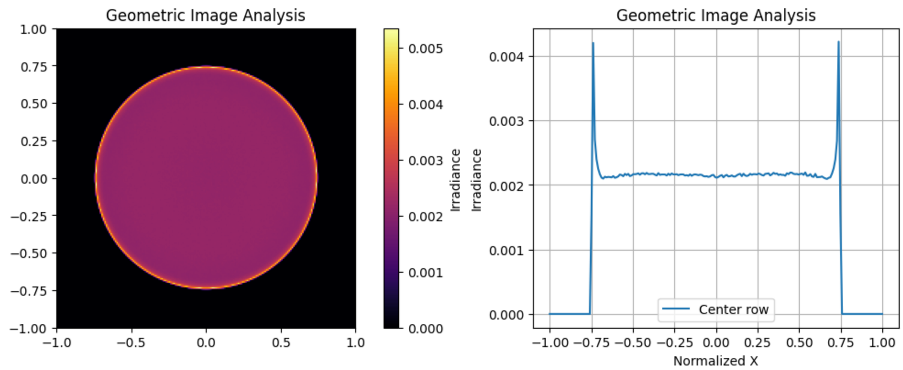

Figure 18: Output beam profile at the output plane after optimization with up to 4th order of the first aspheric as variable.

2.4.2 Optimized with up to 6th order of the first aspheric

After optimization with up to 6th order as variable, the lens data is:

		Surface Type	Comment	Radius	Thickness	Material	Coating	Clear Semi-Dia	Chip Zone	Mech Semi-Dia	Conic	TCE x 1E-6	2nd Order Term	4th Order Term	6th Order Term
1		Standard	Dummy	Infinity	10.000			4.050	0.000	4.050	0.000	0.000			
2	STOP	Standard		Infinity	3.000	1.46,0.0 M		4.050	0.000	4.050	0.000	0.000			
3		Even Asphere		11.037 V	150.000			4.050	0.000	4.050	-26.958 V	0.000	0.000	-4.561E-04 V	1.031E-05 V
4		Standard		Infinity	0.000			12.312	0.000	12.312	0.000	0.000			
5		Standard		80.144 V	3.000	1.46,0.0 M		12.350	0.000	12.375	-96.551 V	0.000			
6		Standard		Infinity	10.000			12.375	0.000	12.375	0.000	0.000			
7	IMAGE	Standard		Infinity	-			12.532	0.000	12.532	0.000	0.000			

Figure 19: Optimized Galilean type beam shaper system with up to 6th order of the first aspheric as variable.

Which gives an output beam profile with a slightly wider flat top region than the 4th order case and no obvious peaks:

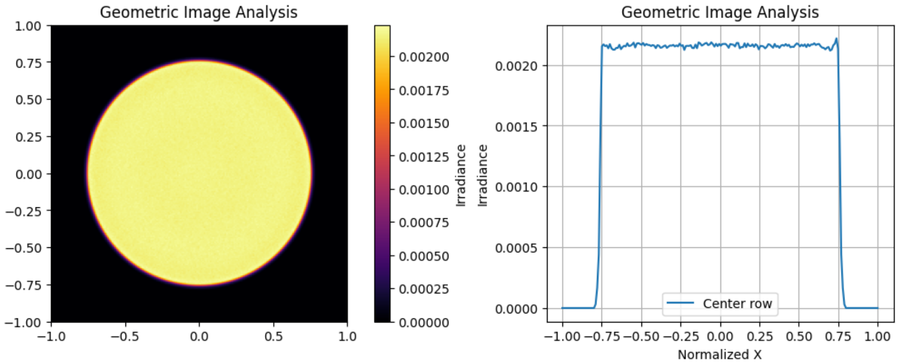

Figure 20: Output beam profile at the output plane after optimization with up to 6th order of the first aspheric as variable.