Gauss-Bessel Axial Intensity Shaping

From Standard to Uniform Axial Intensity

Part of the Beam Shaping Solution Guide

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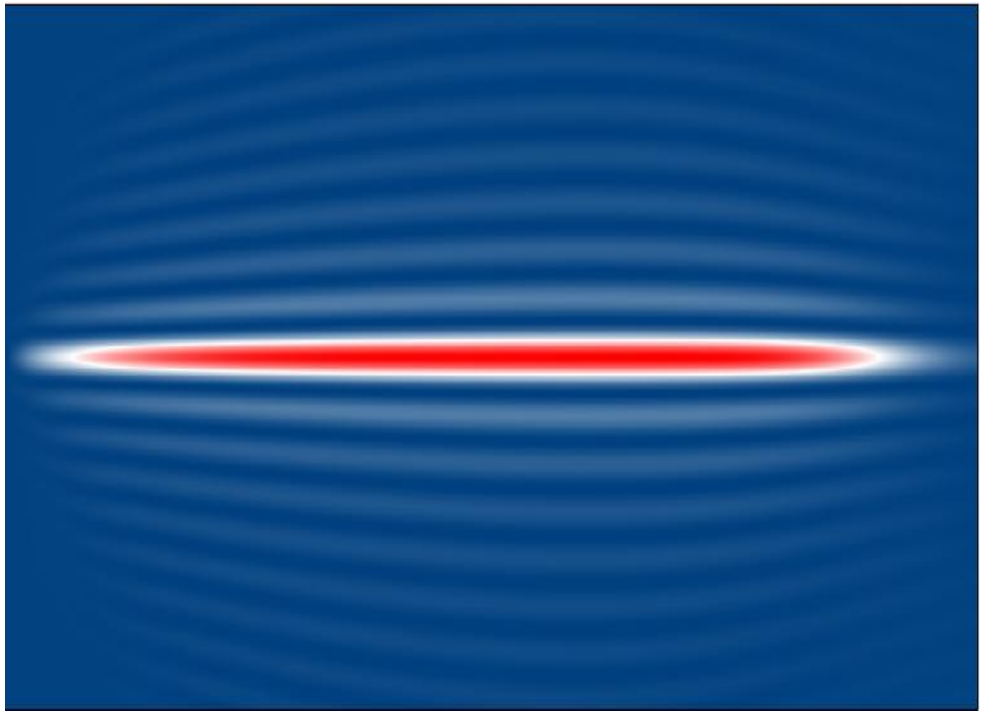
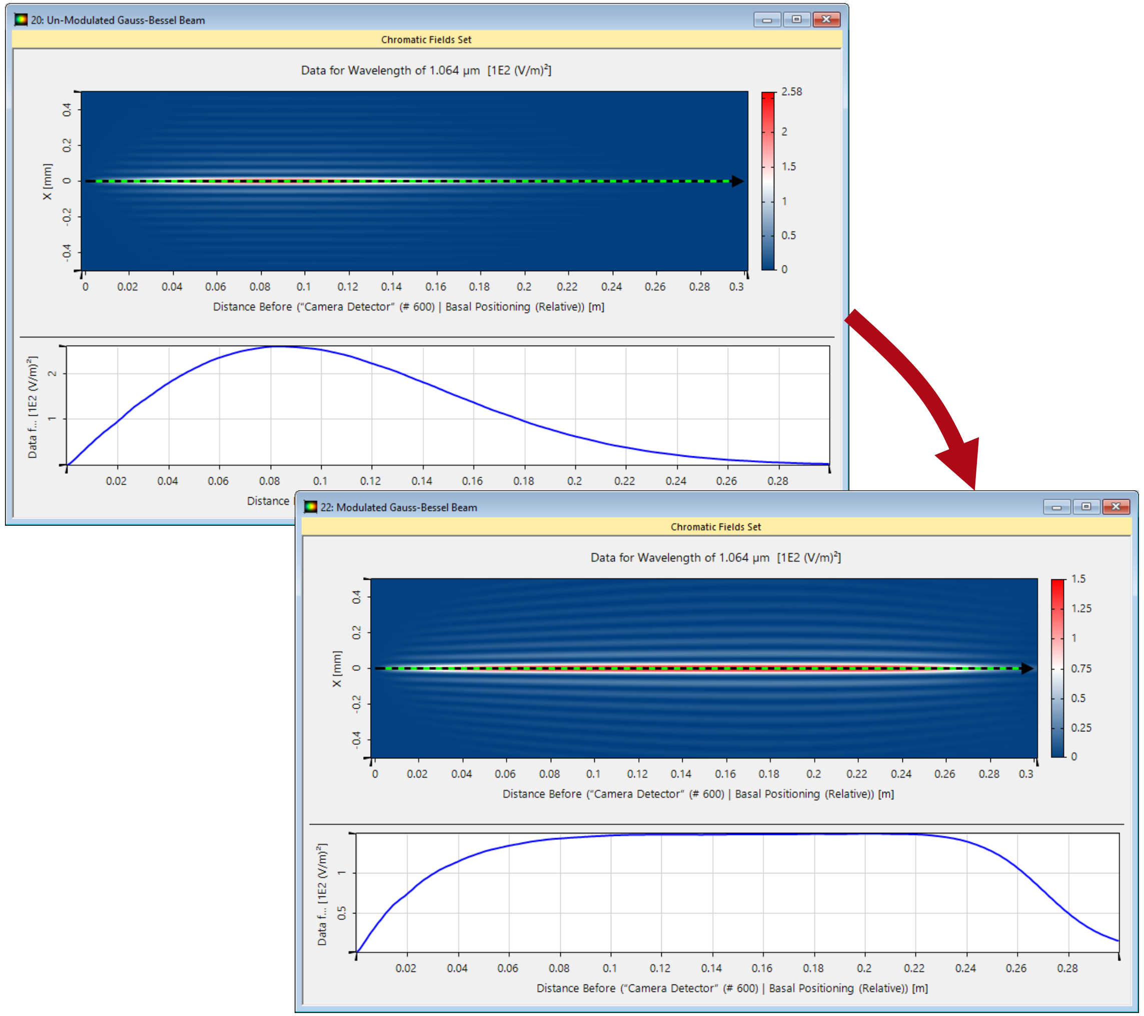


Executive Summary

❓ Can we homogenize the axial intensity of a Gauss-Bessel beam?

✔ Yes. A regular Gauss-Bessel beam exhibits a natural axial intensity profile. By adding a Gaussian modulation to the phase function of a standard axicon, we achieve a homogenized axial intensity distribution.



Key Observations

- Standard axicon: natural axial intensity variation
- Modulated axicon: homogenized axial profile
- Non-diffracting core preserved in both cases

Application Scenario

The Scenario

Standard axicons generate Gauss-Bessel beams with a natural axial intensity variation. We compare the axial intensity profiles of a standard versus a modulated Gauss-Bessel beam using the modulated axicon twin.

Physical Lab Setup

Component	Specification
Laser source	1064 nm, Gaussian, waist radius of 2 mm
Diffractive axicon (modulated)	Phase mask, $\theta = 0.6752°$, optional Gaussian modulation
Translation stage	Moves detector along optical axis (0-300 mm)
Detector	Camera Detector, 1×1 mm^2, 501x501 pixels

Reference Paper & Parameter Origin

Modulated Axicon Phase Function

The twin applies a phase mask with transmission $t(\mathbf{r}, \phi) = \exp(i\Phi_{\text{total}})$, where:

$$\Phi_{\text{total}}(\mathbf{r}, \phi) = -k_0 \sin\theta \cdot \rho + l\phi - A \exp\left(-\frac{|\mathbf{r} - \mathbf{r}_c|^2}{(r_m w_0)^2}\right)$$

with $k_0 = 2\pi/\lambda$, $\rho = |\mathbf{r}|$, and ϕ the azimuthal angle. The first term is the standard axicon phase, the second is the optional vortex (l), and the third is the Gaussian modulation.

Values Adopted from the Paper

Parameter	Value
Gaussian beam waist radius	$w_0 = 2\,\text{mm}$
Refractive axicon	Apex angle $\alpha_0 = 1.5°$ Refractive index $n = 1.45$
Diffractive axicon cone angle (in air)	$\theta = 0.6752°$ (from $\sin\theta = \left(\frac{n_{\text{axicon}}}{n_{\text{air}}}\sin\alpha_0\right) - \alpha_0$)
Modulation magnitude*	$A = 55$
Modulation radius*	$r_m = 1.0$ (relative to w_0)
Modulation center	$(x_c, y_c) = (0, 0)$

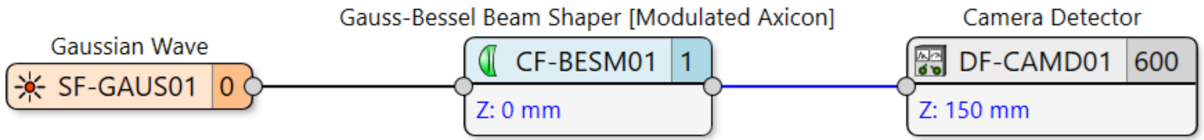
* The paper shows these values produce a long, uniform axial intensity profile (quasi-Bessel beam).

Source

"Quasi-Bessel beam generation by a diffractive axicon with an exponential phase function" Moon et al., Optics & Laser Technology 177, 111059 (2024)

From Real Asset to Digital Twin

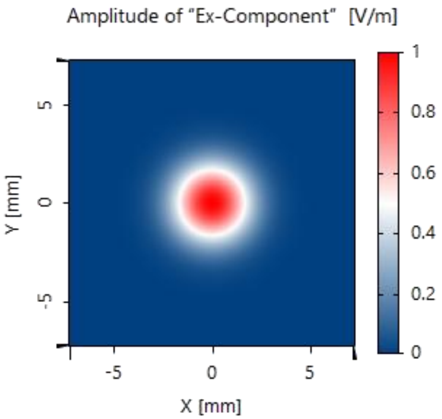
System Layout

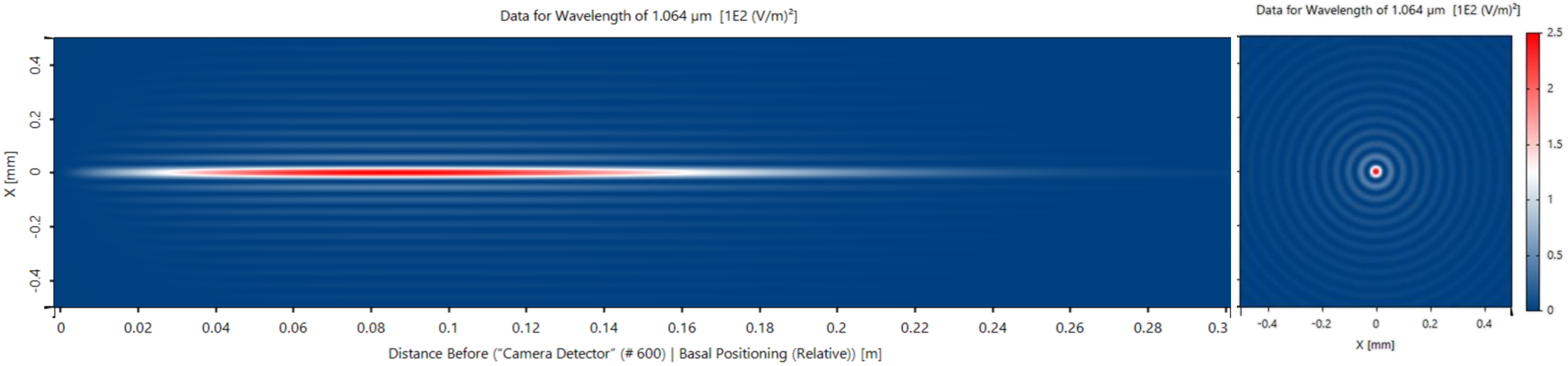


Digital Twin Mapping

Real Asset	Digital Twin	Description
Gaussian laser	SF-GAUS01	$\lambda = 1064\,$nm, $w_0 = 2\,$mm, collimated
Modulated diffractive axicon	CF-BESM01	$\theta = 0.6752°$, $A = 0$ or 55, $r_m = 1$, center (0,0)
Moving camera detector	DF-CAMD01	$1 \times 1\,$mm^2, 501x1 pixels, z sweep 0-300 mm (101 steps)

Optical System Overview - Standard Axicon

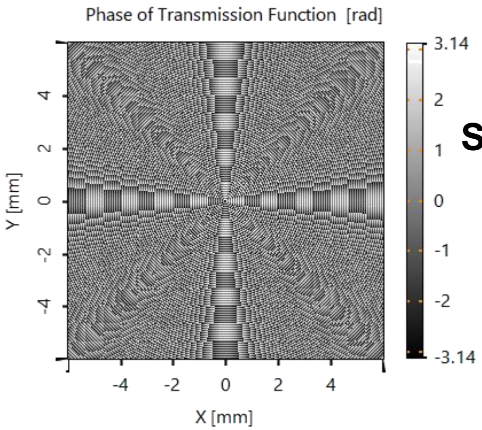




Gaussian wave source

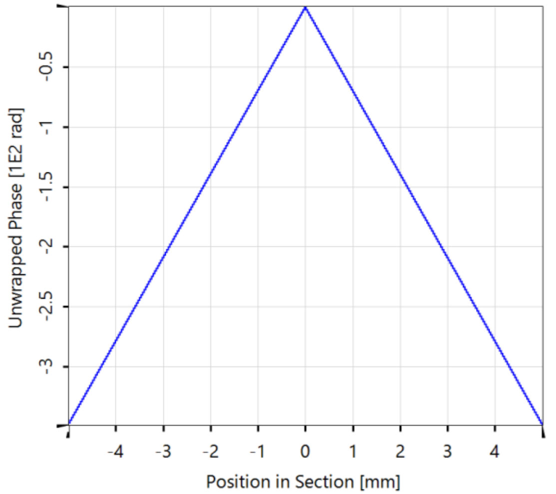
- Radius: 2 mm × 2 mm
- Wavelength: 1064 nm
- Ex polarized

Bessel beam shaper



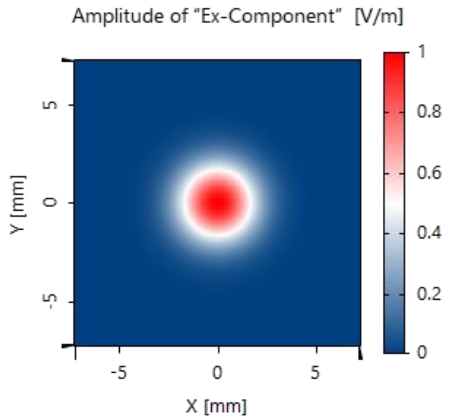
Shaper Config:

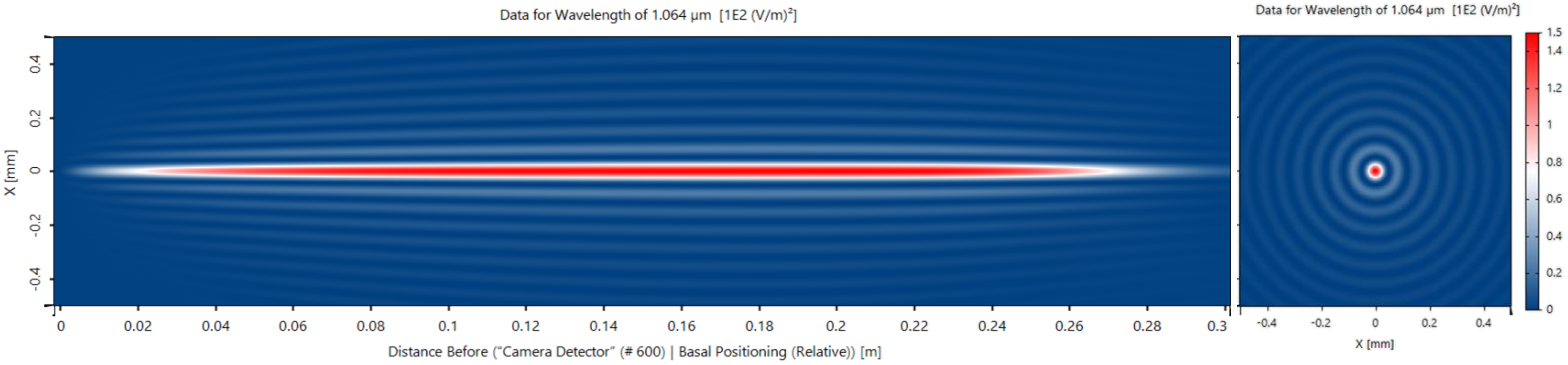
- Angle (θ): 0.67
- Topological Charge: 0
- Case 1: Modulation Magnitude = 0



Unwrapped phase profile of standard axicon phase

Optical System Overview - Modulated Axicon





Gaussian wave source

- Radius: 2 mm × 2 mm
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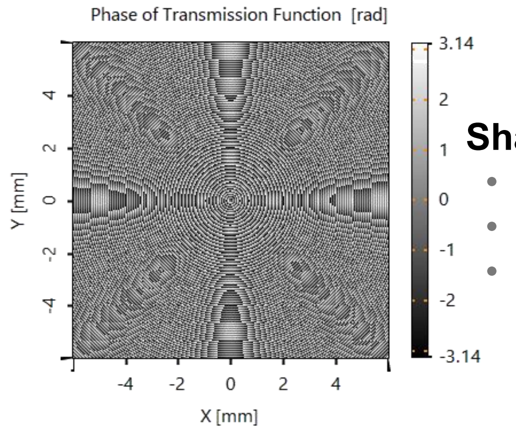
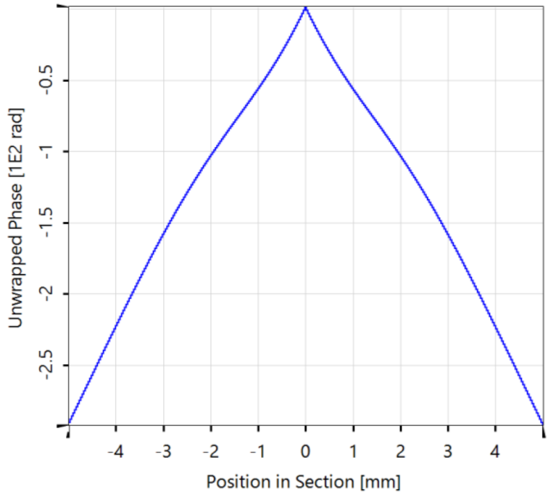
- Ex polarized

Bessel beam shaper



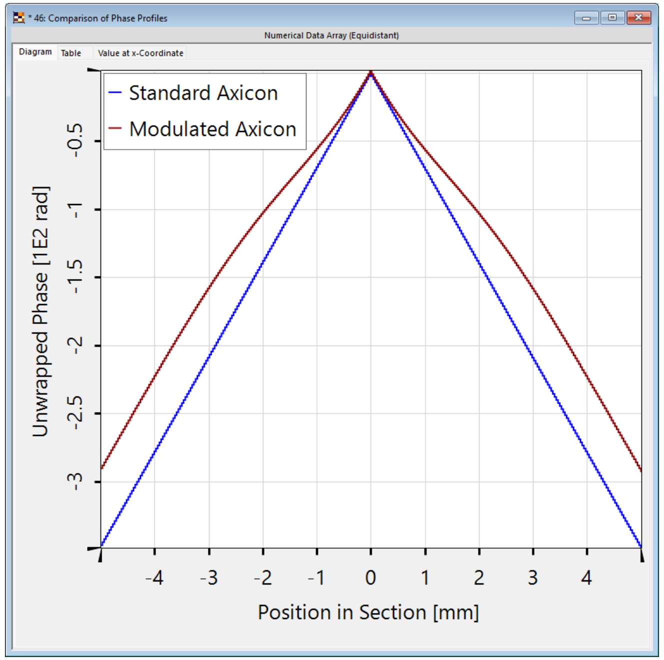
Shaper Config:

- Angle (θ): 0.67
- Topological Charge: 0
- Case 2: Modulation Magnitude = 55

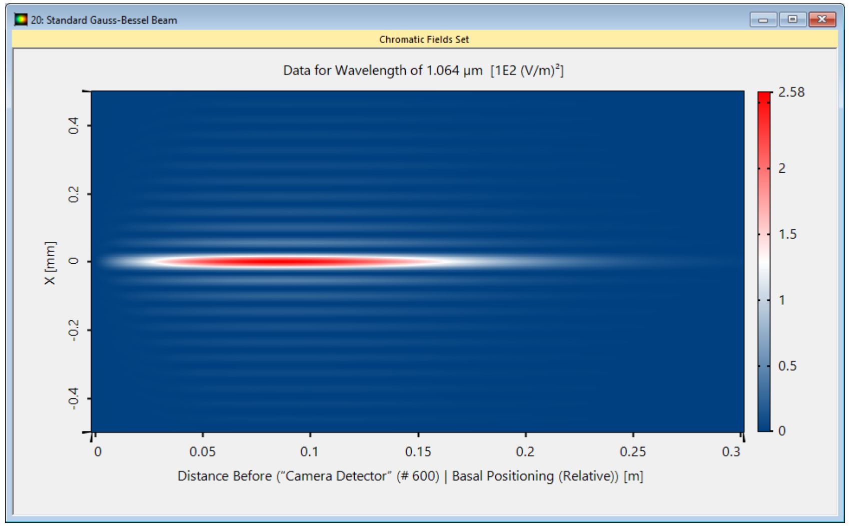


Unwrapped phase profile of modulated axicon phase

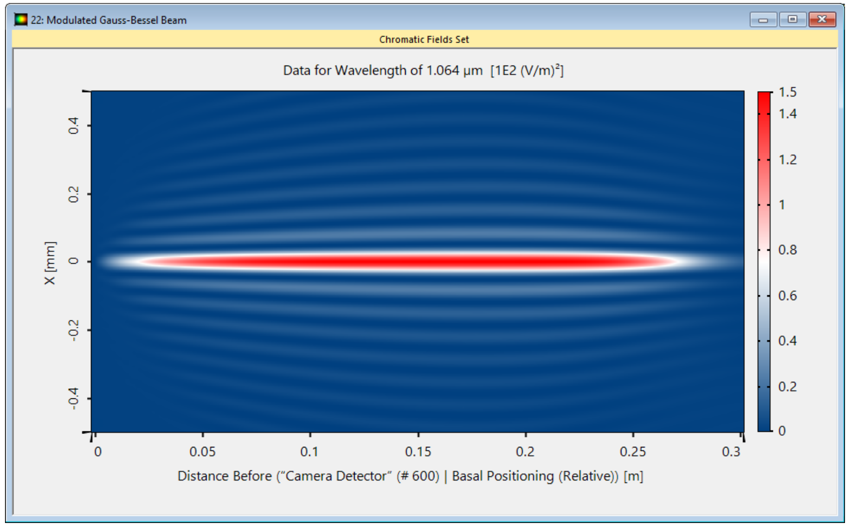
Measured Axial Intensity Profiles



Comparison of Phase Profiles



Standard Gauss-Bessel beam

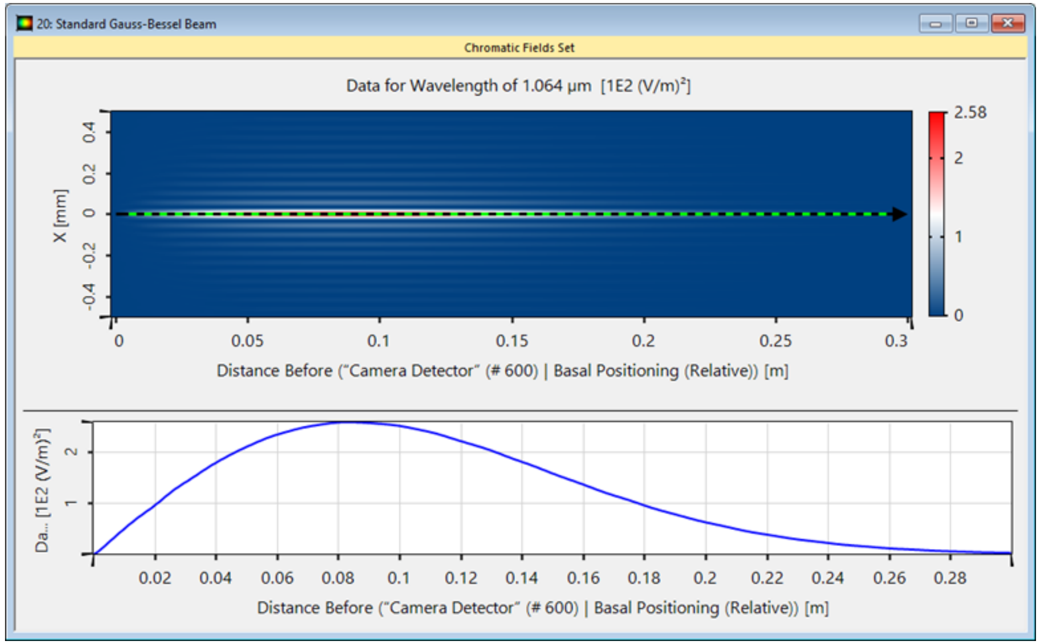


Modulated Gauss-Bessel beam (Homogenized)

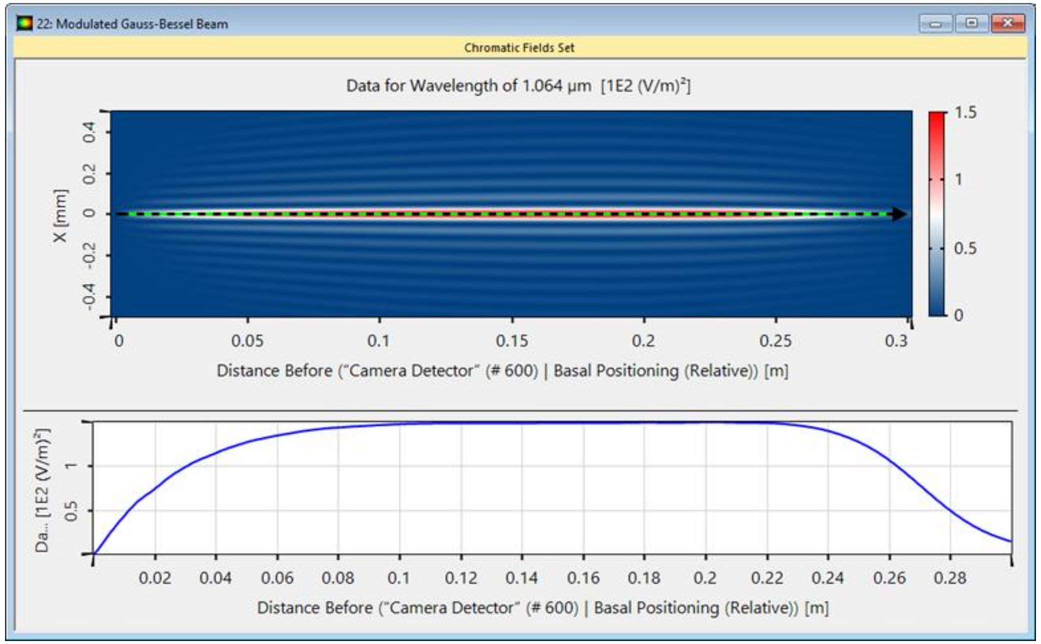
Physics Insight

- **Standard ($A = 0$):** Natural axicon phase.
- **Modulated ($A = 55$):** Axion phase modulate with a Gaussian function

Measured Axial Intensity Profiles (1-D Profiles)



Standard Gauss-Bessel beam



Modulated Gauss-Bessel beam (Homogenized)

Physics Insight

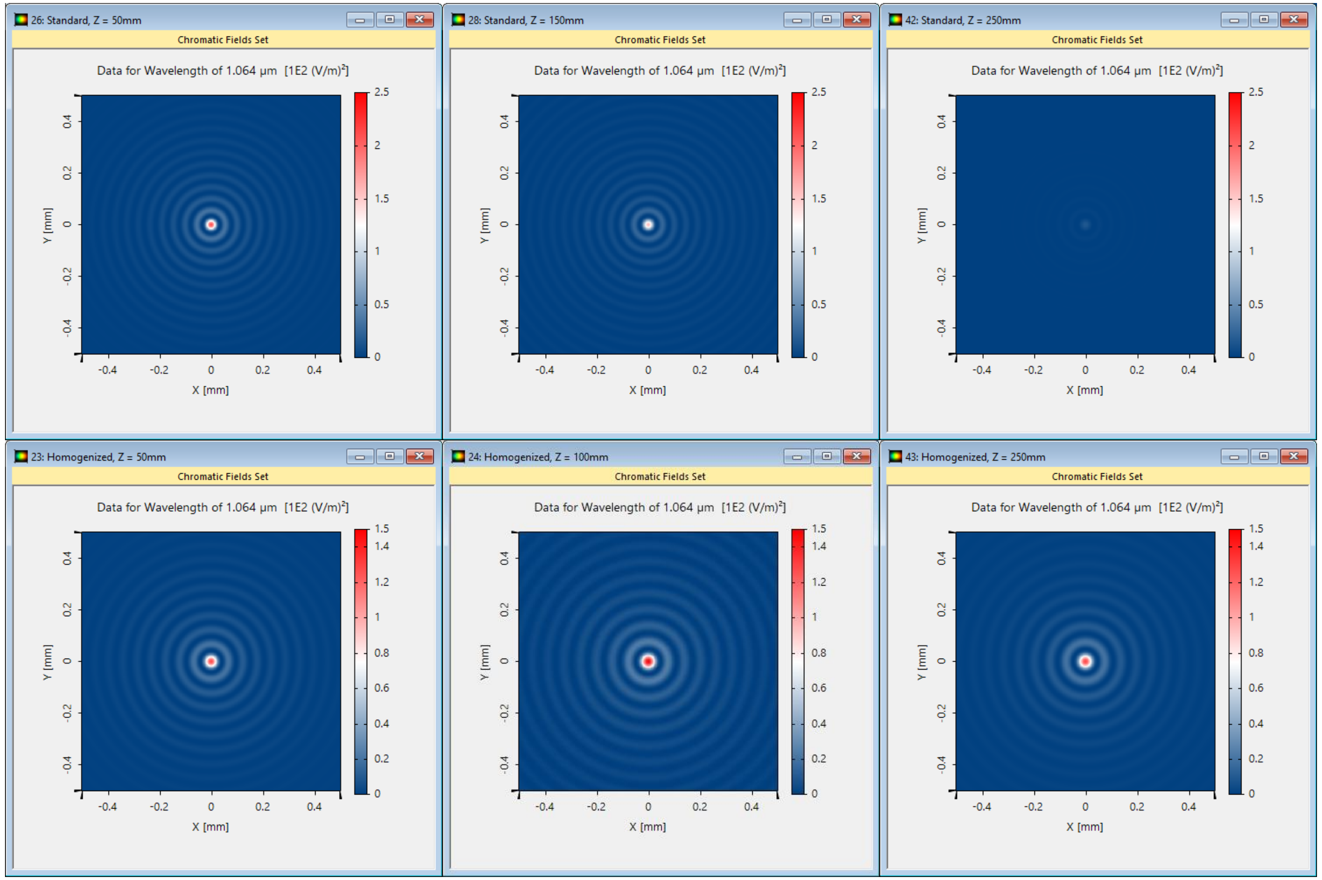
- **Standard ($A = 0$):** Natural axial intensity variation.
- **Modulated ($A = 55$):** Homogenized axial profile over most of the range (50-250 mm).
- Non-diffracting nature of the beam is preserved in both cases.

Results - Transverse Profiles

Selected z Positions

Standard

Homogenized



Z = 50mm Z = 150mm Z = 250mm

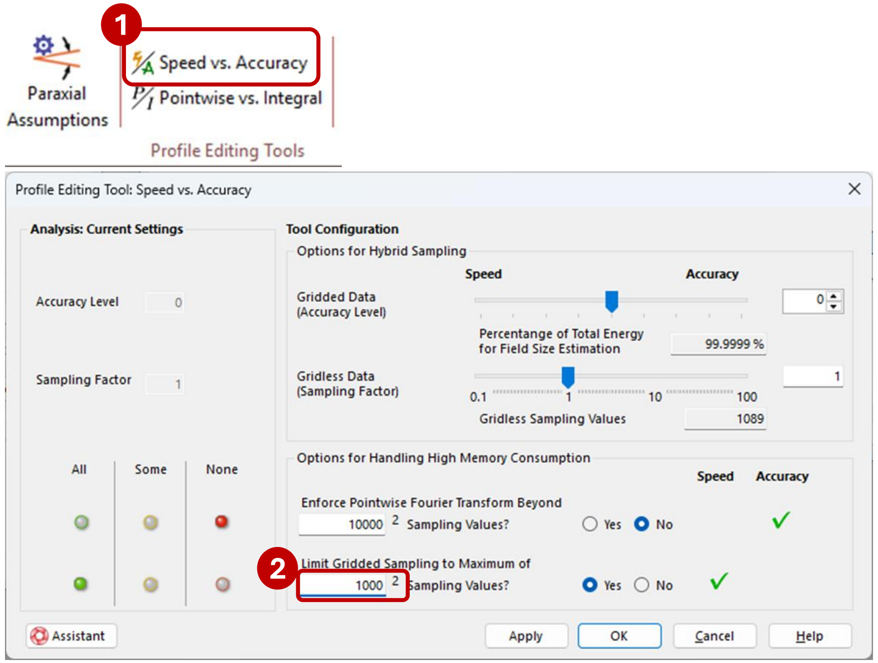
Physics Insight

- Both axicons produce Gauss-Bessel ring structure.
- Modulation homogenizes axial intensity without altering transverse shape.
- For $A = 55$, ring contrast remains high even at extended depth of focus.

Demonstrated Workflow

Step-by-Step Workflow

1. **Setup:** Place Gaussian source, Gauss-Bessel Beam Shaper [Modulated Axicon], and Camera detector.
2. **Sampling:** Reduce the sampling limit from 10,000 to 1000 points squared. This significantly speeds up the simulation while keeping reasonable accuracy.
3. **Standard case:** Set modulation magnitude $A = 0$ (all other parameters as in Key Parameters section).
4. **Axial sweep:** Perform parameter run for position z across the specified range; record intensity profiles.
5. **Modulated case:** Set modulation magnitude $A = 55$, repeat parameter run.
6. **Analysis:** Compare axial intensity profiles to observe homogenization.



Configuring speed-accuracy settings

Performance

Simulation time: $\approx$ 1 minute for 101 positions of parameter run
Hardware: Intel i7-12700K @ 3.6 GHz • 12 cores • 32 GB RAM

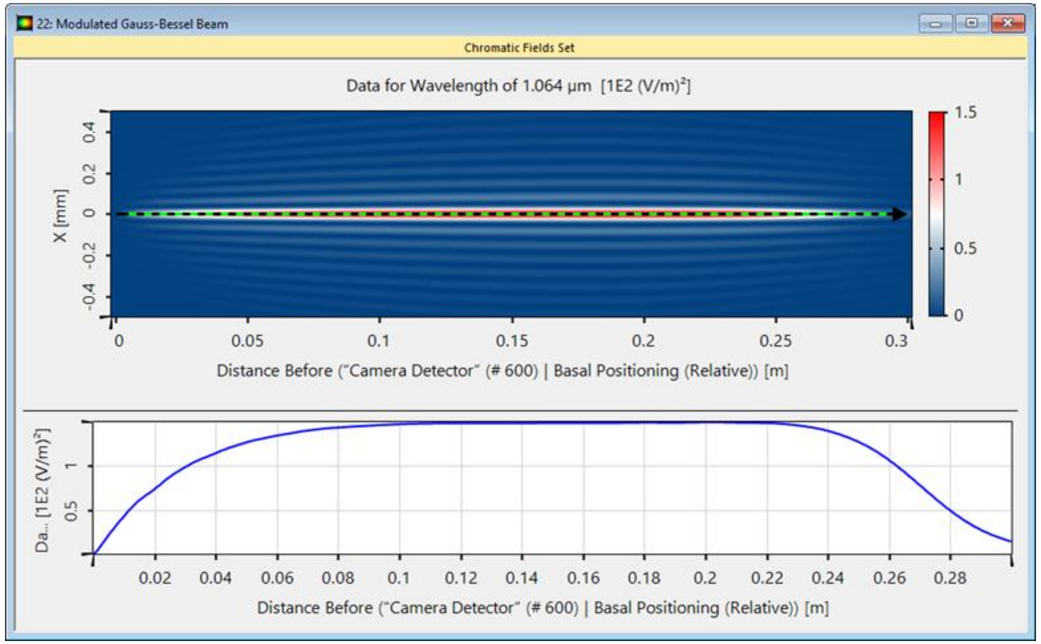
Conclusion

Key Takeaways

- Modulated axicon twin (CF-BESM01) successfully homogenizes axial intensity of Gauss-Bessel beams
- With $A = 55$, $r_m = 1$, a uniform axial profile is achieved over $\approx$200 mm range
- Transverse Bessel profile preserved – non-diffracting character unchanged
- Simple parameter sweep workflow allows direct comparison between standard and modulated designs

Next Steps

- Optimize modulation magnitude A and radius r_m for specific application (e.g., laser cutting depth)
- Combine with vortex charge ($l > 0$) for homogenized dark-core beams
- Export designed phase for fabrication on SLM or DOE



Modulated Gauss-Bessel beam (Homogenized)

Download the sample file. Shape your beam.

References & Resources

Specification Sheets

- `SF-GAUS01` – Gaussian Beam Source
- `CF-BESM01` – Gauss-Bessel Beam Shaper [Modulated Axicon]
- `DF-CAMD01` – Camera Detector

Technical Papers

1. Moon, J. B., Lee, H. R., Han, G. W., & Kim, J. W. (2024). Quasi-Bessel beam generation by a diffractive axicon with an exponential phase function. *Optics & Laser Technology*, *177*, 111059. https://doi.org/10.1016/j.optlastec.2024.111059

2. Daniel Flamm, Daniel Günther Grossmann, Michael Jenne, Felix Zimmermann, Jonas Kleiner, Myriam Kaiser, Julian Hellstern, Christoph Tillkorn, Malte Kumkar, "Beam shaping for ultrafast materials processing," Proc. SPIE 10904, Laser Resonators, Microresonators, and Beam Control XXI, 109041G (4 March 2019); https://doi.org/10.1117/12.2511516