Towards a High-Concentration Line-Focus Concentrator: Étendue-Squeezing and Tracking Integration

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1 Background

Conventional line-focus concentrators are limited by the 2D concentration limit, which is orders of magnitudes lower than the 3D concentration limit of point-focus systems [1]. Here, we show that it is possible to design a trough-like line-focus concentrator not limited by the 2D concentration limit, and we demonstrate that this type of concentrator can be combined with tracking-integration to achieve the required two-axis solar tracking.

2 Methods

We combined étendue-squeezing and tracking integration as outlined below, and created two example designs using numerical optimization.

- Assuming ideal 100% reflective mirrors.
- Simulated sunlight with top-hat ±9mrad angular distribution, to account for the angular size of the sun convolved with surface errors.
- Optimized with Python/Numba-based raytracer, on resources provided by the NTNU IDUN/EPIC computing cluster [2].

3 Approach: Ẽtendue squeezing and tracking integration

Étendue squeezing [3] has previously been used for lighting applications [4] and proposed for refractive solar concentrators [5]. Fig. 1 shows how the approach can be extended to reflective trough-like solar concentrators. The resulting concentrator requires two-axis solar tracking, which can be implemented by combining single-axis external tracking as shown in Fig. 2 with tracking integration as shown in Fig. 3.

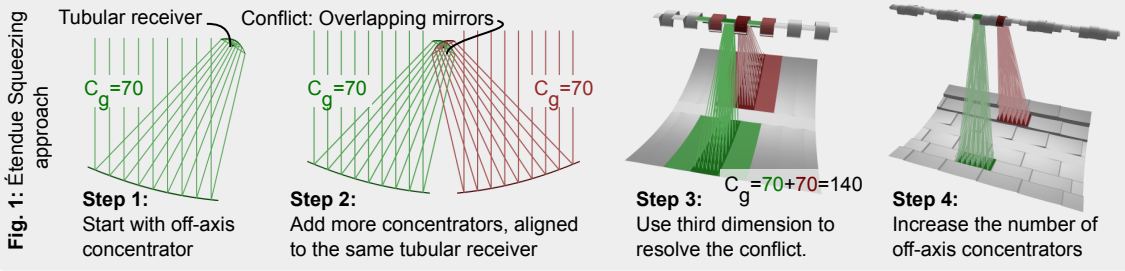


Fig. 1: Étendue Squeezing approach

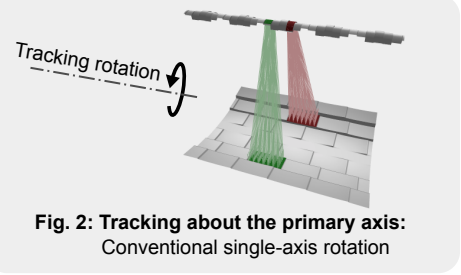


Fig. 2: Tracking about the primary axis: Conventional single-axis rotation

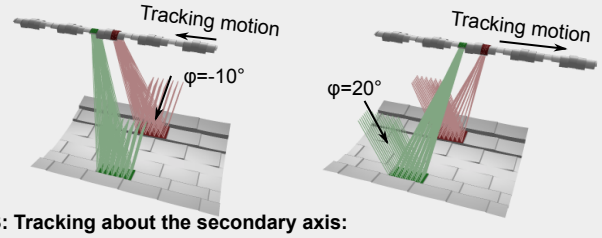
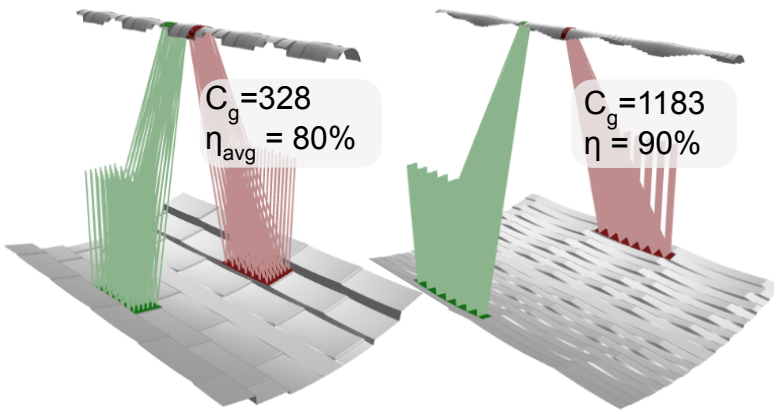


Fig. 3: Tracking about the secondary axis: Tracking integration, through lateral translation of secondary mirror

4 Results



Design 1
Optimized for tracking integration, assumed to be installed with north-south aligned external tracker at 30° latitude. η_{avg} is simulated average yearly efficiency.

Design 2
Optimized for maximum concentration. Does not support tracking integration, and needs two-axis external tracking.

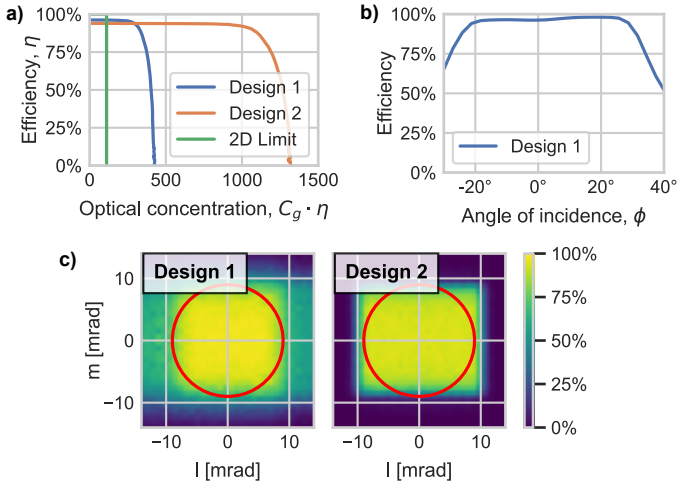


Fig. 4: a) Efficiency vs concentration, showing that both designs outperform the 2D concentration limit. **b)** Performance of integrated tracking in Design 1. **c)** Angular acceptance of the two designs. Red circles represent the ±9mrad angular extent that the designs are optimized for.

5 Summary

- The combination of étendeue squeezing and tracking integration can be used to design line-focus concentrators with high concentration ratios and high tolerance to tracking errors, while maintaining the mechanical and practical benefits of a line-focus system with tubular receivers.
- We showed an example for single-axis external tracking, achieving 80% average yearly efficiency at 328x geometric concentration. This is above the 2D concentration limit of 111x at the 9 mrad acceptance half-angle.
- We further showed that an étendue-squeezing concentrator designed for two-axis external tracking can reach 1183x geometric concentration with 90% efficiency and a 9 mrad acceptance half-angle.

6 References

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[3] P. Benítez, J. C. Miñano, J. Blen, O. Dross, and F. García, "Étendue squeezing optics: Beating the angle-space compromise of symmetrical systems" in International Nonimaging Optics Workshop (2005)
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