Parametric Optimization of Fiber Coupling Lenses
Fibers are some of the most versatile components in modern optics. One of their most valued characteristics is their capacity to transport optical energy with very low losses across vast distances (even several kilometers). On the flip side, coupling light into a fiber in a way that achieves as high an efficiency as possible is often a very delicate endeavor: among other things, the fiber coupling lens must be well designed to ensure that the focal spot matches the propagating modes of the fiber as closely as possible. With the fast physical optics simulation and the parametric optimization in VirtualLab Fusion, we show the design of a plano-convex lens with a conical surface for the task of coupling light into a single-mode fiber.
Design Task

conical surface
- radius of curvature $R = ?$
- conical constant $k = ?$

How to optimize the fiber coupling lens to achieve maximum efficiency, by an appropriate selection of values of the lens parameters (radius of curvature $R$, conical constant $k$, and lens thickness $t$)?

input field
- fundamental Gaussian
- wavelength 780 nm
- diameter 660 µm

coupling lens (initial parameters from Edmund 65254)
- effective focal length 2 mm

single-mode fiber
- mode field diameter = 3 µm

$\begin{align*}
\text{t} &= ? \\
\text{d} &= 1.585 \text{ mm} \\
(\text{fixed working distance})
\end{align*}$
Lens systems, such as the coupling lens in this application, can either be configured by the user from scratch or imported from information provided by the manufacturer.
The Singlemode Fiber Coupling Efficiency Detector calculates the efficiency as the normalized overlap integral of the incoming field and the (single) eigenmode of the fiber. Please note that, as its name implies, this detector only works for a singlemode fiber.
In order to find an optimized set of parameters for the lens, the *Optimization* document enables the definition of parameter constraints and weights for the target values. Find more information under:

[Introduction to the Parametric Optimization Document](#)
### Summary – Components...

![Diagram of optical system components](image)

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Evaluation of Initial Lens

Initial lens parameters
- radius of curvature \( R = 1.7 \text{ mm} \)
- conical constant \( k = 0 \)
- lens thickness \( t = 0.8 \text{ mm} \)

The coupling efficiency obtained from the initial spherical lens is not optimal, due to mismatch between the focal spot of the lens and the propagating mode of the fiber.

Coupling efficiency \( \eta = 88.4\% \)
(overlap integral calculation)
Parametric Optimization

Initial lens parameters
- radius of curvature $R=1.7\, \text{mm}$
- conical constant $k=0$
- lens thickness $t=0.8\, \text{mm}$

$\eta = 88.4\%$

optimized lens parameters
- radius of curvature $R=1.608\, \text{mm}$
- conical constant $k=-0.7139$
- lens thickness $t=0.6311\, \text{mm}$

$\eta = 99.6\%$

parametric optimization of coupling efficiency with downhill simplex algorithm
Evaluation of Optimized Lens

Optimized lens parameters
- radius of curvature $R = 1.608 \text{mm}$
- conical constant $k = -0.7139$
- lens thickness $t = 0.6311 \text{mm}$

The coupling efficiency increases to almost the ideal theoretical value after optimization of the lens.

Coupling efficiency $\eta = 99.6\%$ (overlap integral calculation)
VirtualLab Fusion Technologies

- Free space
- Prisms, plates, cubes, ...
- Lenses & freeforms
- Gratings
- Diffractive, Fresnel, meta lenses
- HOE, CGH, DOE
- Micro lens & freeform arrays
- SLM & adaptive components
- Diffractive beam splitters
- Waveguides & fibers
- Scatterer
- Diffusers
- Crystals & anisotropic components
- Nonlinear components
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**Further Reading**

- [Optimal Working Distance for Coupling Light into Single-Mode Fibers](#)
- [Comparison of Different Lenses for Fiber Coupling](#)
- [Introduction to the Parametric Optimization Document](#)