COMSOL Multiphysics® Implementation of a Genetic Algorithm Routine for Metasurface Optimization

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Background

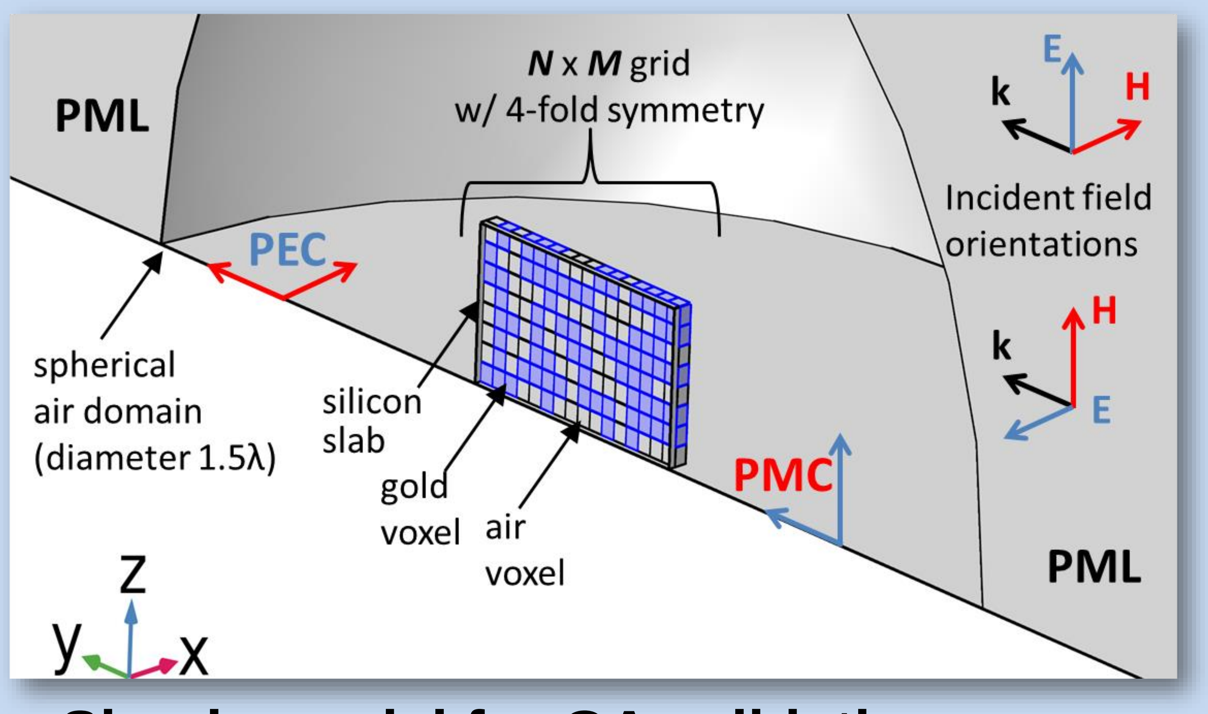
- Planar 2-D plasmonic metasurfaces are **limited in both phase control and intensity** that make it poor for optical application
- Subwavelength 3-D structures can support out-of-plane scatters for **improved phase control without polarization conversion**
- Genetic algorithms provide a means to **optimize** these scatterers for a target phase and amplitude—necessary for efficient lens design

Goals

- Use COMSOL Multiphysics® with LiveLink for MATLAB™ to **develop genetic algorithm** (GA) routine
- **Validate GA routine** using a simple model of an MxN grid of gold and air voxels to create a superior forward scatterer (Huygens source)
- Apply validated GA code to **optimize** a grid design at a desired phase point and maximum transmission for construction of metasurface lens

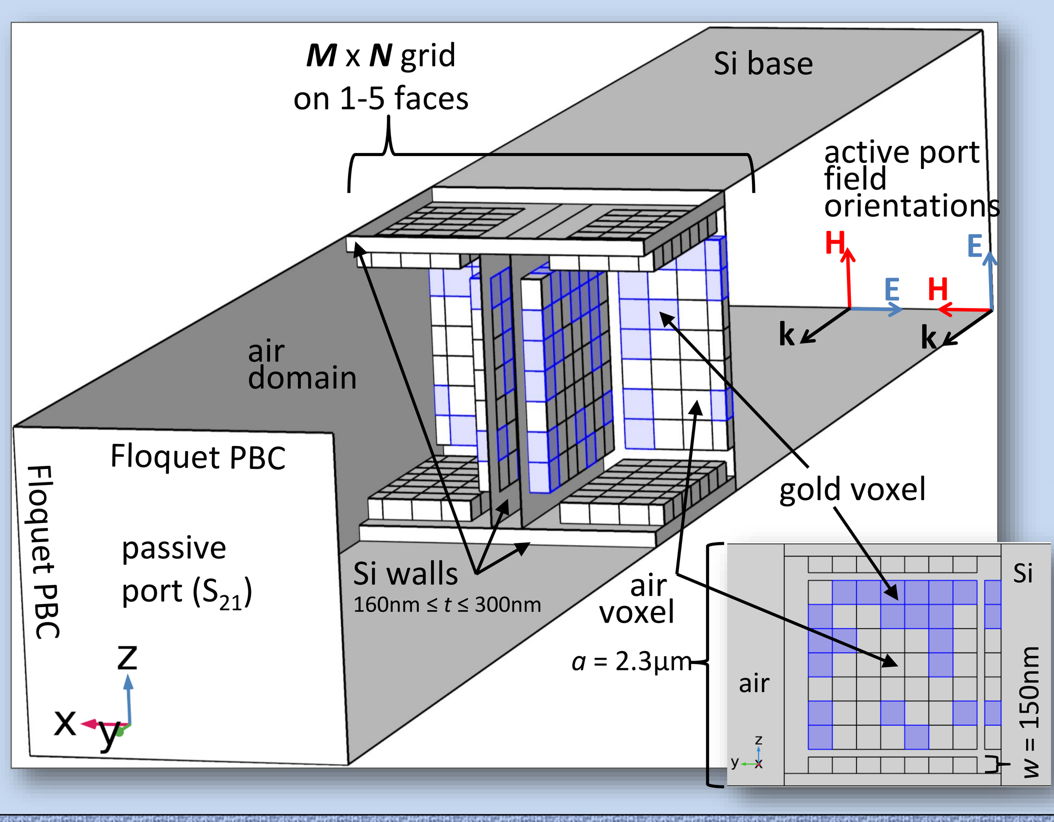
Modeling Approach

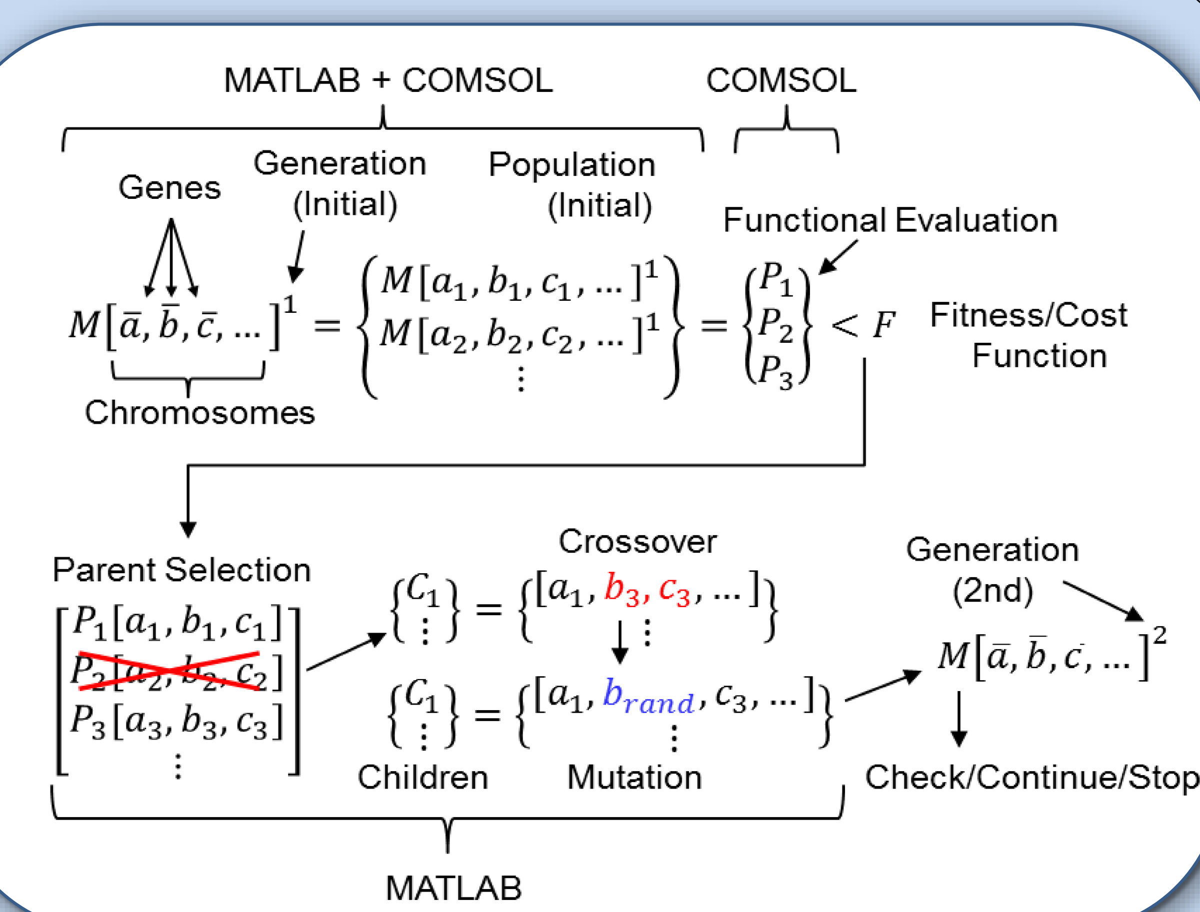
- Use COMSOL application programming language (API) to build and solve GA population.
- Randomly populate MxN grid of voxels with binary "1" for gold and "0" for air.
- GA code iterates with COMSOL to determine optimal grid layout



Simple model for GA validation

Metasurface model





COMSOL w/ LiveLink for MATLAB GA Process

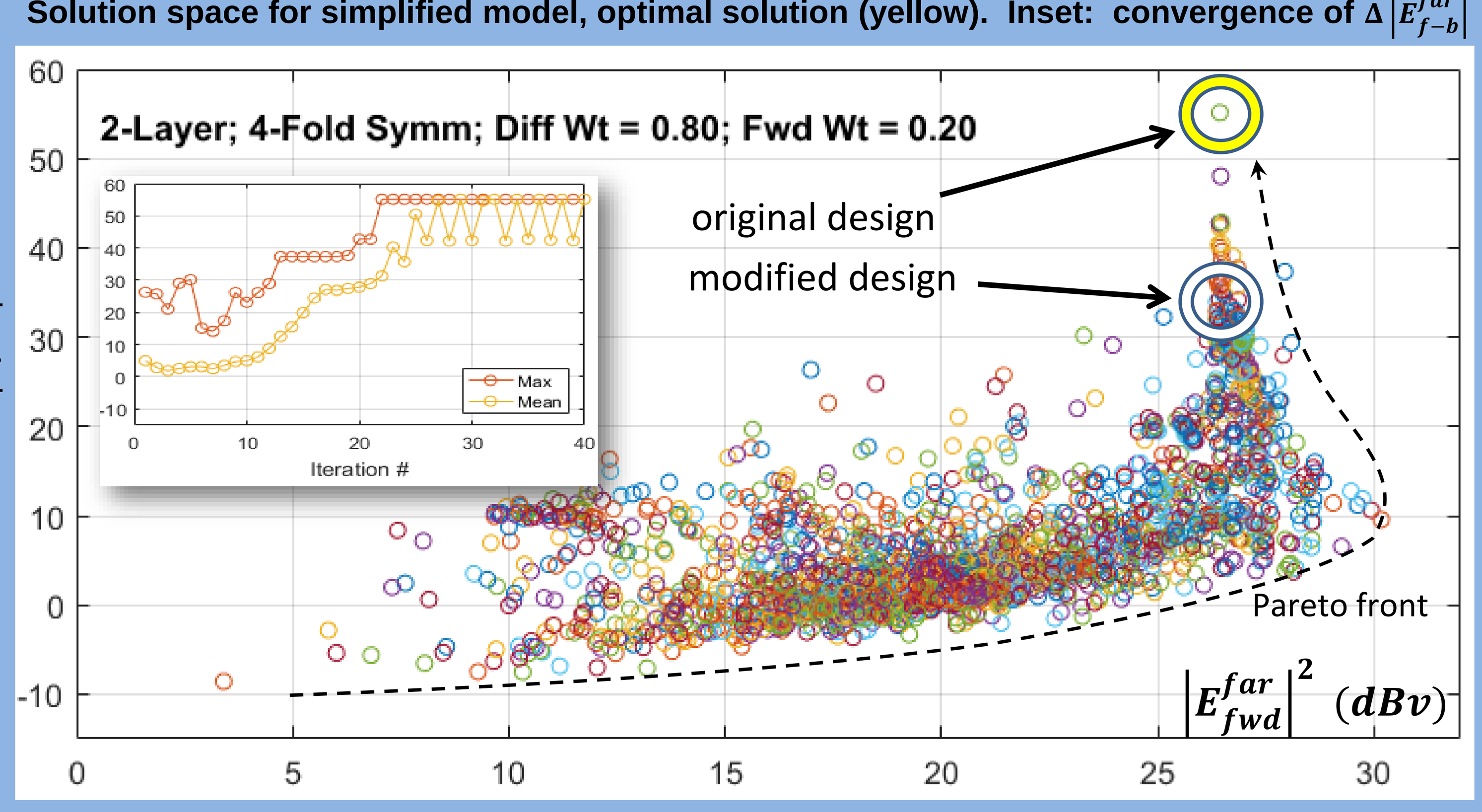
Validation of COMSOL GA Routine

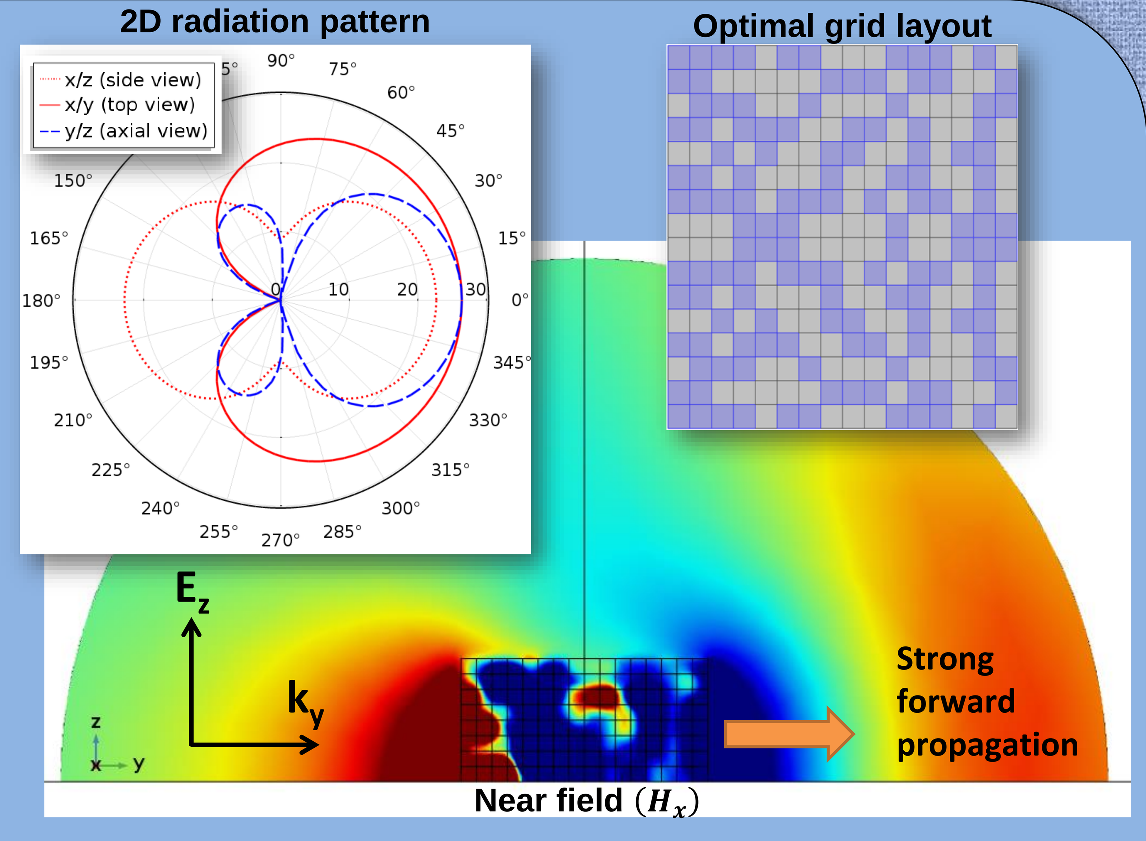
- Solving for maximum forward scattered far-field ($|E^f|^2$) and maximum difference between forward/backward scatter $\Delta|E|^2$
- Dual-objective fitness/cost function:

$$F(w_\Delta, w_f) = w_\Delta \frac{\Delta|E|^2 - \min(\Delta|E|^2)}{\max(\Delta|E|^2) - \min(\Delta|E|^2)} + w_f \frac{|E^f|^2 - \min\left(|E^f|^2\right)}{\max(|E^f|^2) - \min(|E^f|^2)}$$

- "Best" solution: $+26\ dBv$ forward, $-28\ dBv$ back
- Convergence after 22 iterations

Solution space for simplified model, optimal solution (yellow). Inset: convergence of $\Delta|E^{far}_{f-b}|^2$



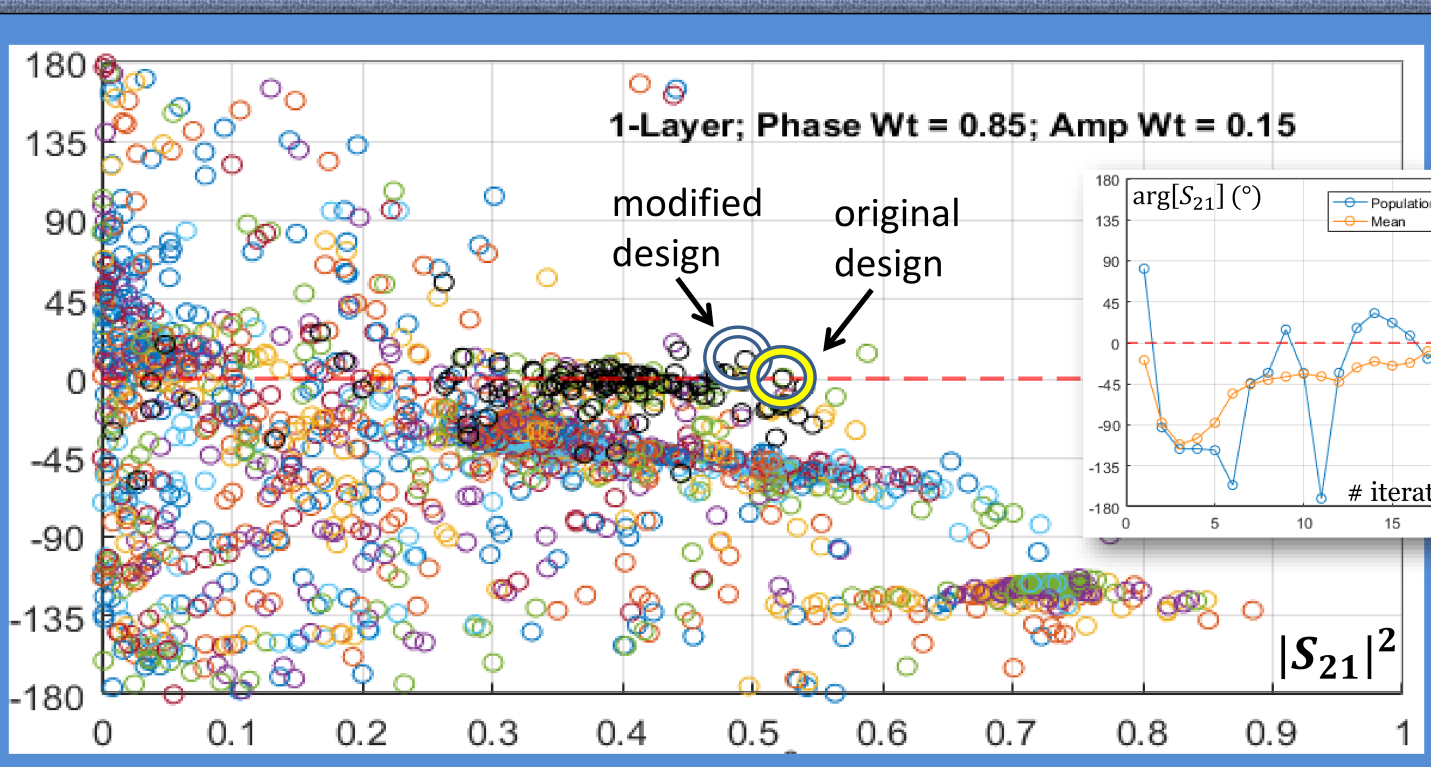


GA Optimization of Metasurface

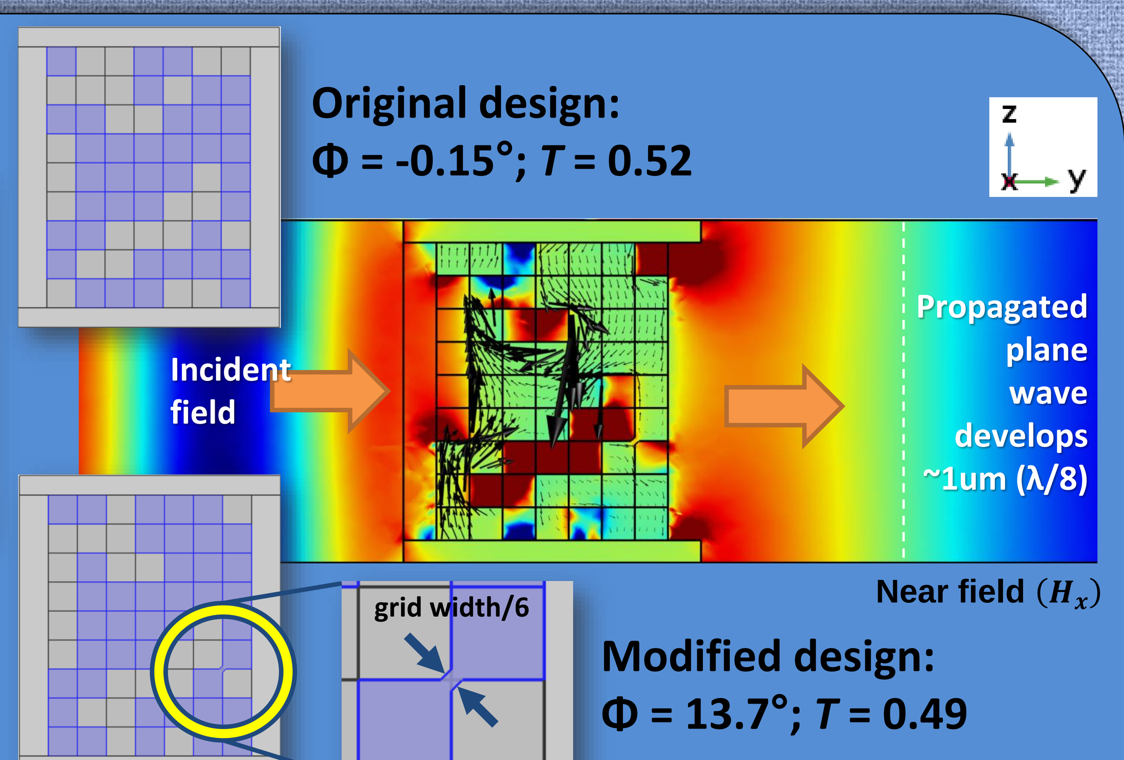
- Now solving for maximum transmission ($|S_{21}|^2$) at target phase point
- Dual-objective fitness/cost function:

$$F(w_\Phi, w_f) = w_\Phi \frac{\sigma_\Phi^2}{|\Phi - \Phi_0|^2 + \sigma_\Phi^2} + w_s \frac{\sigma_s^2}{||S_{21}|^2 - T_0| + \sigma_s^2}$$

- Targeted phase: $\Phi = 0°$
- "Best" solution: $\Phi = -0.15°, T = 0.52$
- "Best" couldn't be fabricated, due to closed loops
  - Modified solution: $\Phi = 13.7°, T = 0.49$



Solution space for simplified model, optimal solution (yellow). Inset: convergence of Φ.



Computational Information

- 2 Xeon CPUs/28-cores/256GB RAM
- 5GB solved model/35K mesh/250K DoF
- API + Livelink for MATLAB + Wave Optics module + Wavelength Domain (ewfd)
  - Solution time/per model: ~30sec
  - # of Populations: $2xMxN$ (typically 120)
  - # of Iterations: typically < 20

Conclusions/Future Work

- With COMSOL Multiphysics as the underlying computational mechanism and a process link via LiveLink for MATLAB, a robust GA routine was successfully validated against a simple unit cell model, and then used to produce optimized solution spaces for design of a metasurface lens.
- Individual phase points were targeted accurately—such phase control at high efficiencies (40-50%) is unprecedented for single-layer plasmonic interfaces
- Next: fabricate/measure phase differences to validate models, and build a lens!

References

[1] N. Yu and F. Capasso, "Flat optics with designer metasurfaces," *Nat Mater*, **13**, 139 (2014)

[2] R. Haupt and D. Werner, Genetic Algorithms for Electromagnetics, New York: JWS (2007).

[3] B. Adomanis, "Design of Infrared Metasurfaces for Low-Profile Optics Using COMSOL Multiphysics," COMSOL Conference Technical Papers (2016).