Lab 2: Uniform Grating Coupler

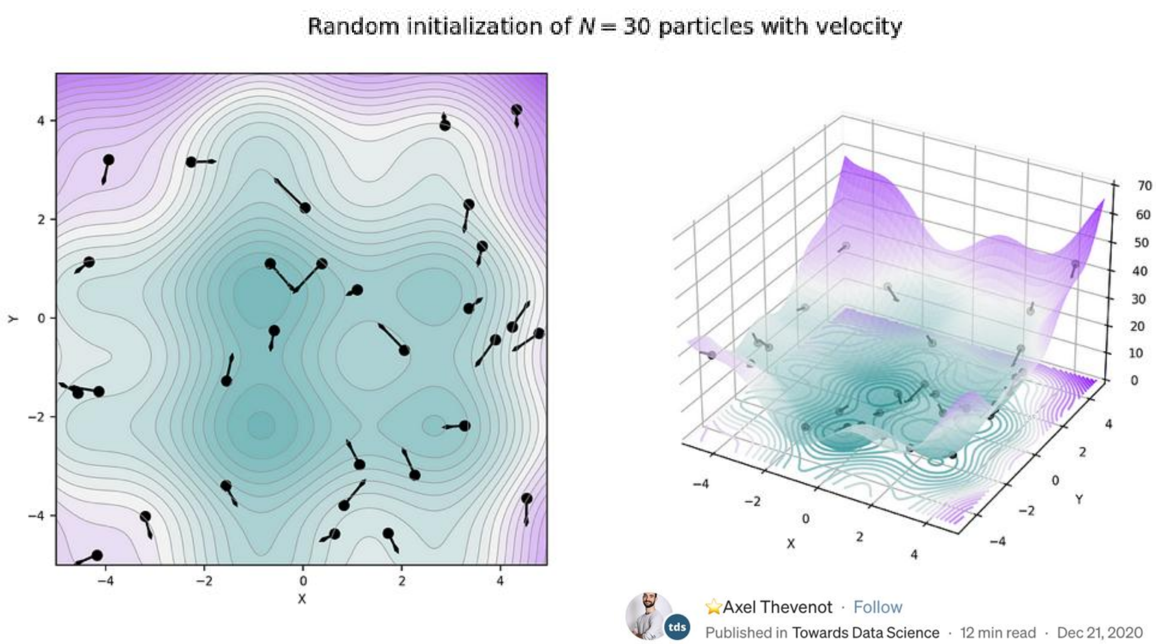
Part 2: Refinement via Parameter Sweeps and Optimizations

Objective:

- Learn how to define and script result extraction in Analysis Mode
- Learn how to refine a uniform grating through parameter sweeps and optimizations.

Background:

Particle Swarm Optimization (PSO) is a nature-inspired optimization algorithm based on the collective behavior of individuals in a group. In PSO, a population of potential solutions, referred to as particles, moves through the search space to find the optimal solution. Each particle adjusts its position and velocity based on its own experience and the best-known position within the group. The algorithm is guided by both personal best and global best positions, promoting collaboration among particles to converge towards the optimal solution over successive iterations. PSO is the default optimization algorithm used in Lumerical.

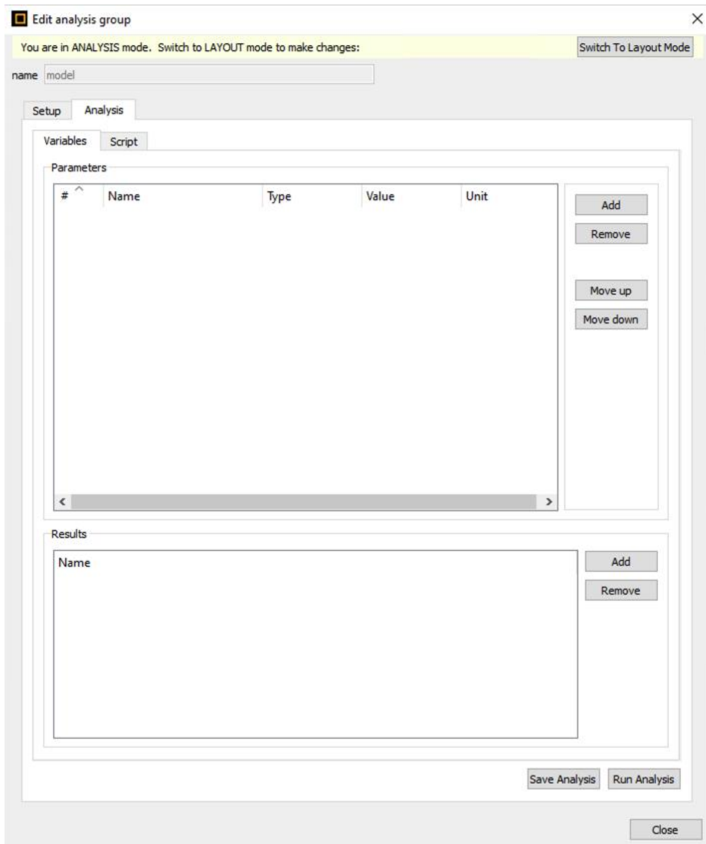


Procedure:

Open Lumerical and load the grating coupler file from Lab 2 Part 1. If you did not complete it, download the ***grating_coupler_2D.fsp*** file from bcourses.

Define the Figure of Merit (FOM)

1. Run the simulation – we need to be in ***Analysis*** mode to interact with the simulation result.
2. Right click on *model* and *edit object* to begin scripting. Select the ***Analysis*** tab
    a. While the *Setup* script is run every time you begin a simulation, the *Analysis* script is run upon execution. We will use this script to interact with the simulation results.

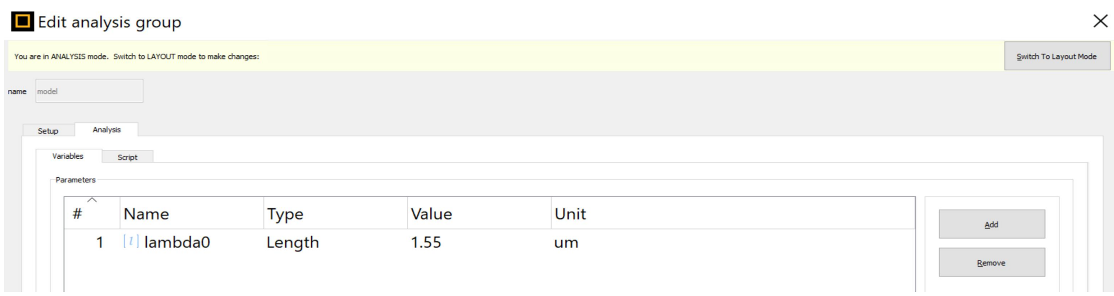


3. Add a ***Result*** in the bottom window. Let's call this *T* – this will be the directionality of the grating, or the fraction of energy radiated upward versus the input energy.

4. Switch to the *Script* sub-tab. Much like how we procedurally generated the grating structure, we will write code to get the transmission of the grating and store it in our result *T*.

```
monitor = 'slice';
T = transmission(monitor);
?('Directionality = ' + num2str(T));
```

Additional Notes (for steps 3 & 4): here is a more general method for extracting results from monitors. Suppose we are simulating multiple wavelengths but only want to extract data for a specific wavelength. We can first define the target wavelength as a variable under the *Analysis* > *Variables* section — let's call it *lambda0*, as shown below.



Next, go to the *Script* section under *Analysis* and enter the following code. Instead of using the built-in *transmission* function, we will use a more general function called ***getresult*** to extract monitor data. This function takes two inputs: the name of the monitor and the specific result to extract.

```
T_data = getresult('::model::FDTD::ports::port 2','T');
T = abs(T_data.T);
lambda = T_data.lambda;
ii = find(lambda,lambda0);
T = T(ii);
?('Directionality = ' + num2str(T));
```

Note that getresult does not return a single value but a structured dataset — typically a matrix with multiple columns, such as wavelengths/frequencies and the result values. To work with this data, you need to separate the relevant arrays. As shown in the second and third lines of the example below, *T_data* contains both the *wavelength/frequency* and *transmission* data. You can access specific fields using:

- `T_data.T` → transmission values
- `T_data.lambda` → wavelength values
- `T_data.f` → frequency values

Finally, the fourth and fifth lines show how to locate the entry in the spectrum that matches your defined *lambda0* and extract the corresponding transmission value.

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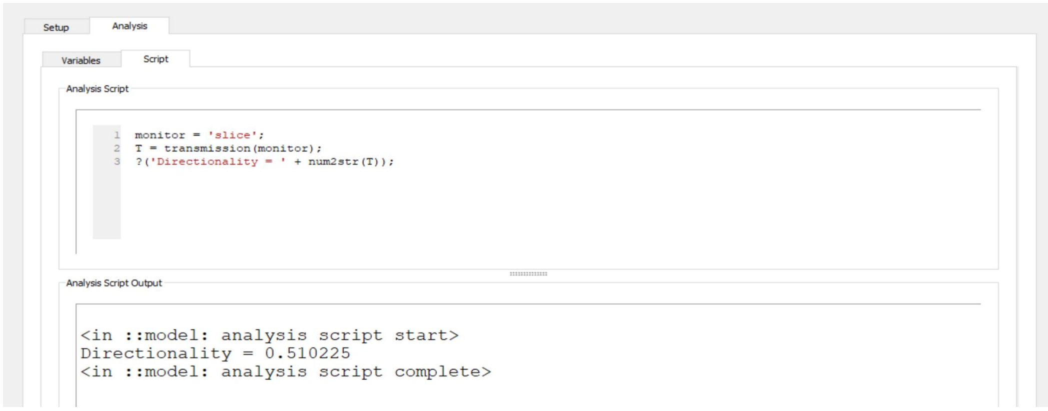
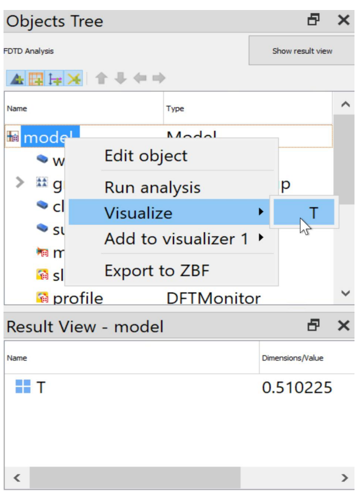
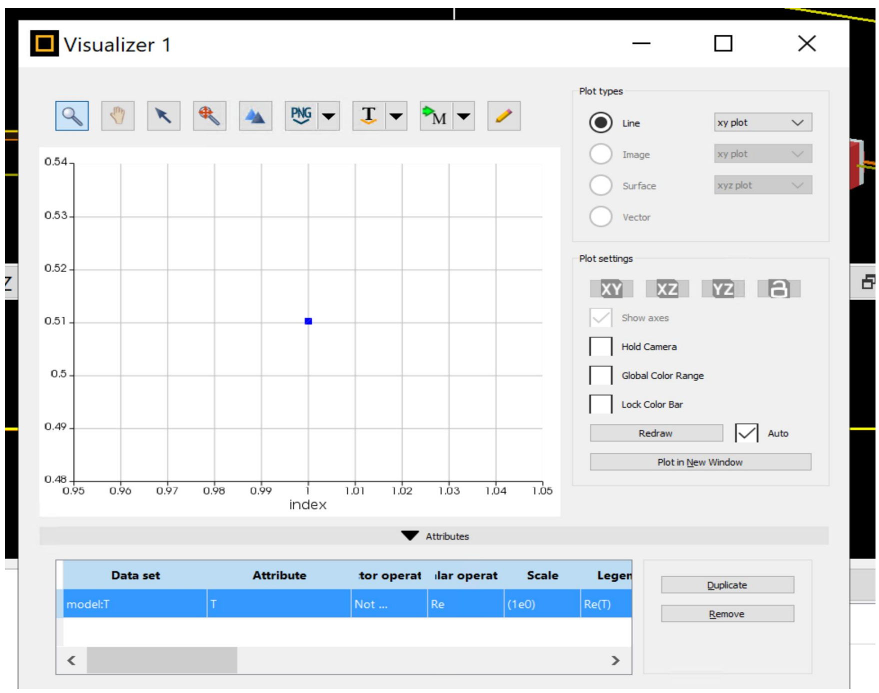
5. Click *Run Analysis* to execute the script. The output will appear as shown below.



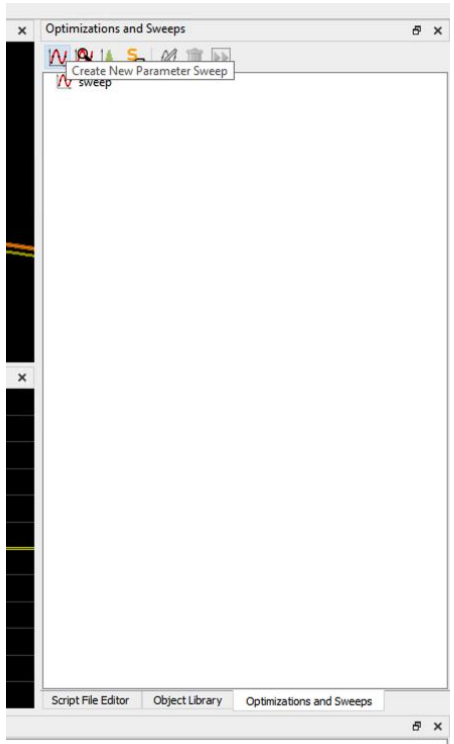
Save Analysis and exit the script. Right click on *Model* and visualize the result. We should see a Visualizer with our transmission result.



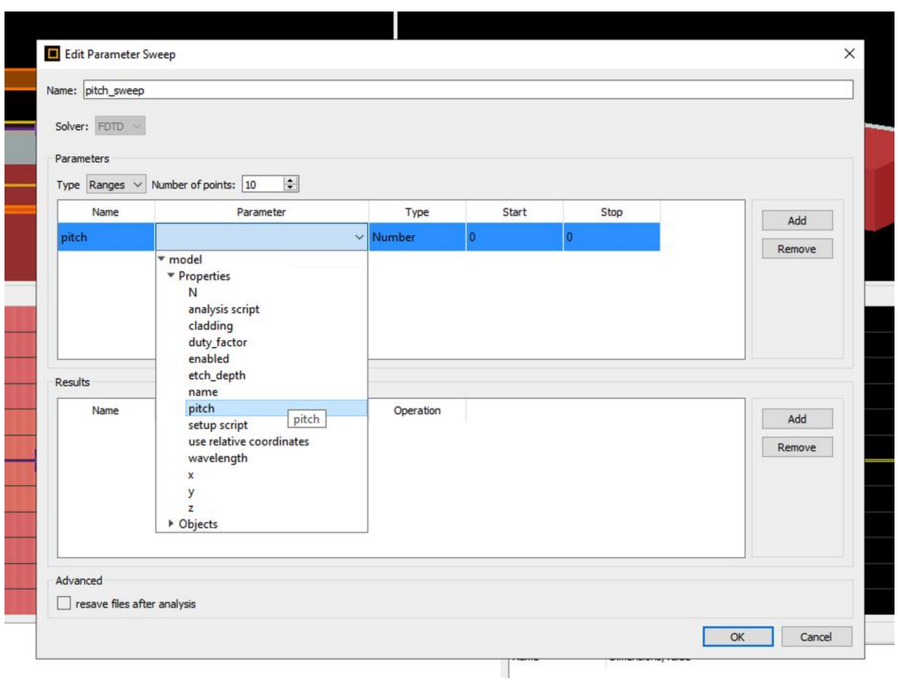


Set up the Parameter Sweep

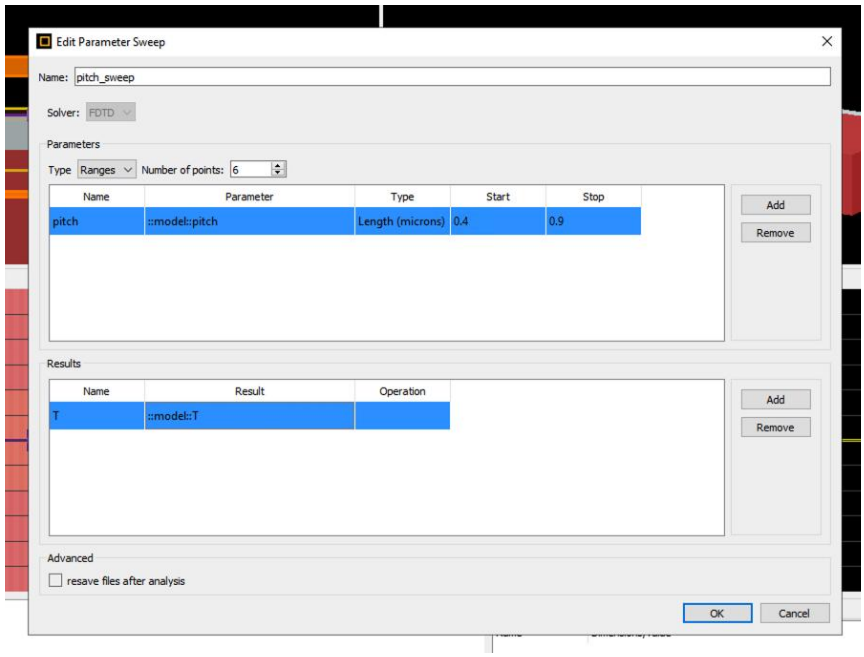
1. Navigate to the *Optimizations and Sweeps* tab on the right side of the window. Click on the graph icon to ***Create a New Parameter Sweep***.



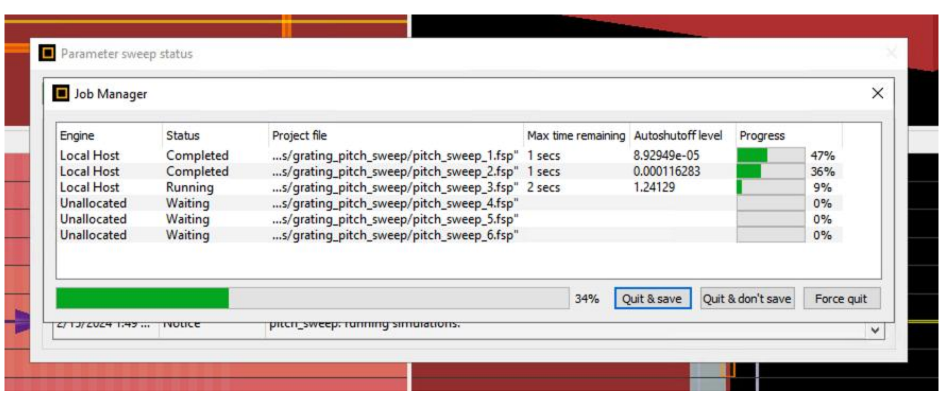
2. The most vital design parameter for a grating coupler is the pitch, so we will sweep that parameter first. Name it *pitch_sweep* and add our variable ***pitch*** as the *Parameter*.



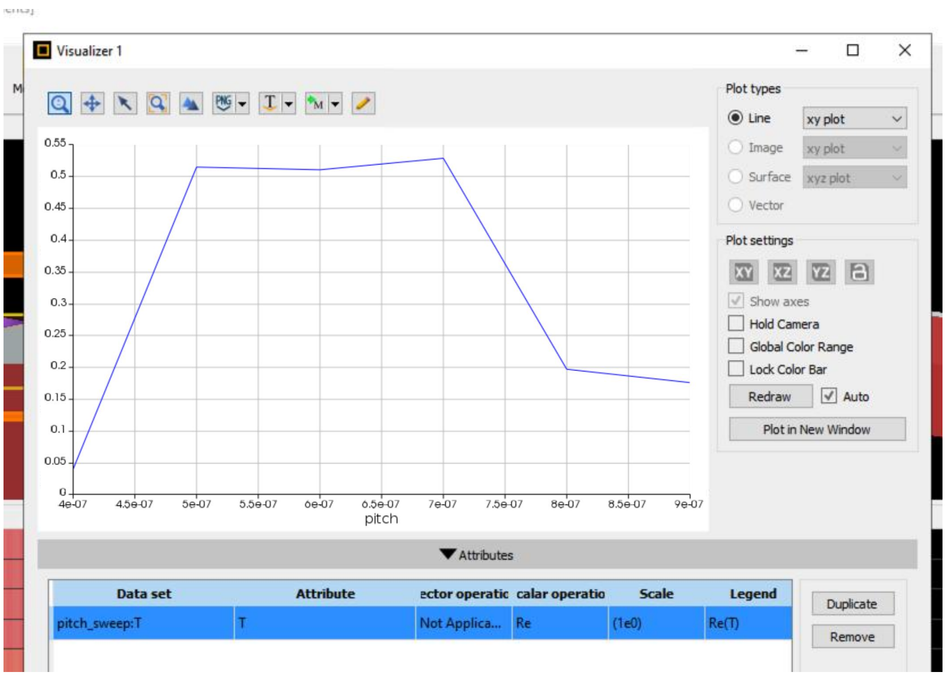
3. Sweep the pitch from 400 nm to 900 nm with a 100 nm interval – this corresponds to 6 points in the sweep. Add our result ***T*** to the *Results* tab.
    a. NOTE: we could add T without scripting the result by selecting ***model::objects::slice::T***. Any result that is already given by a monitor can be selected through the sweep window. However, sometimes you will need to define your own custom result – scripting the result in this manner is good practice.



4. Run the sweep by right clicking on the object and selecting *Run*. Lumerical will generate six new iterations of your script, changing the swept variable for each one. Then, it will sequentially run each individual script.
    a. It is good practice to carefully observe your structure as the sweep commences. In our case, the pitch is our sweeping variable. We should watch the grating rendering to verify that the pitch is changing in a manner we would expect.
    b. For troubleshooting, these individual files are saved in the directory of your original script.

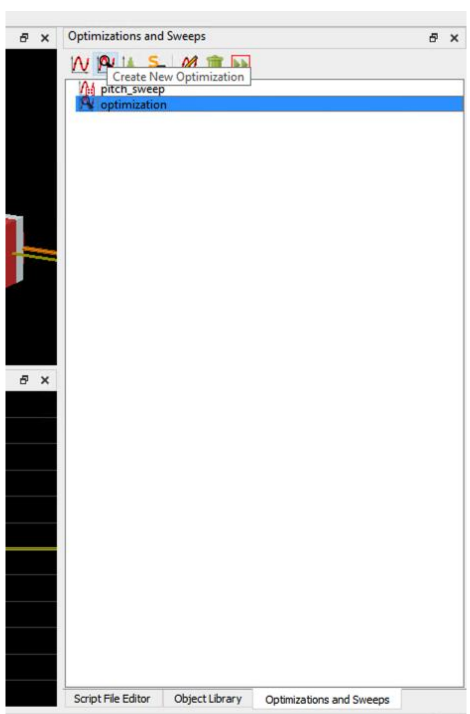


5. Right click on the sweep and visualize the result. Lumerical will automatically collate the requested result(s) from the sub-scripts – in this case, we will see the transmission plotted against the pitch.



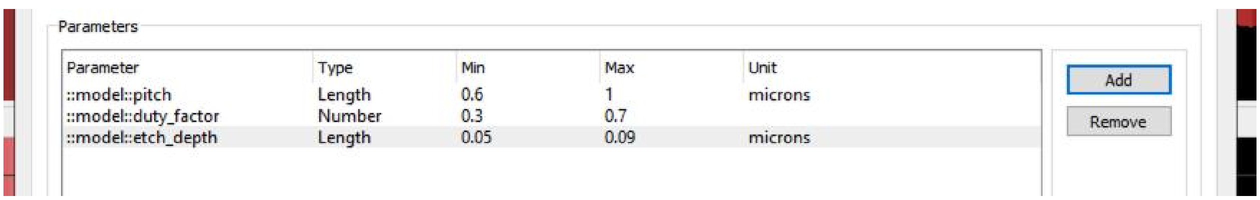
Optimize the Grating Coupler

1. Add an optimization by clicking on the icon next to the sweep button

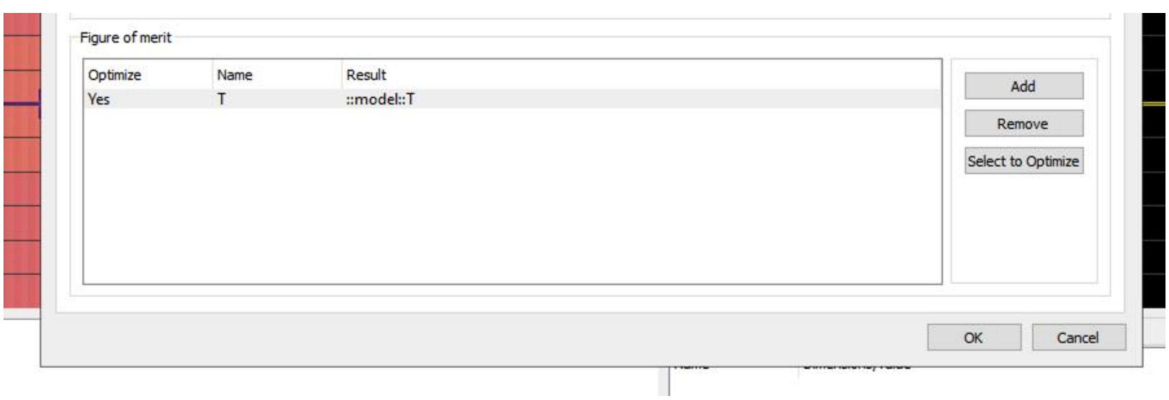


2. Rename the optimization to *T_optimization*. Verify that the *Algorithm* is ***Particle Swarm***, and set the *Maximum generations* to 20 and *Generation size* to 5. Set the *Tolerance* to *0*, and set the *Type* to *Maximize*.

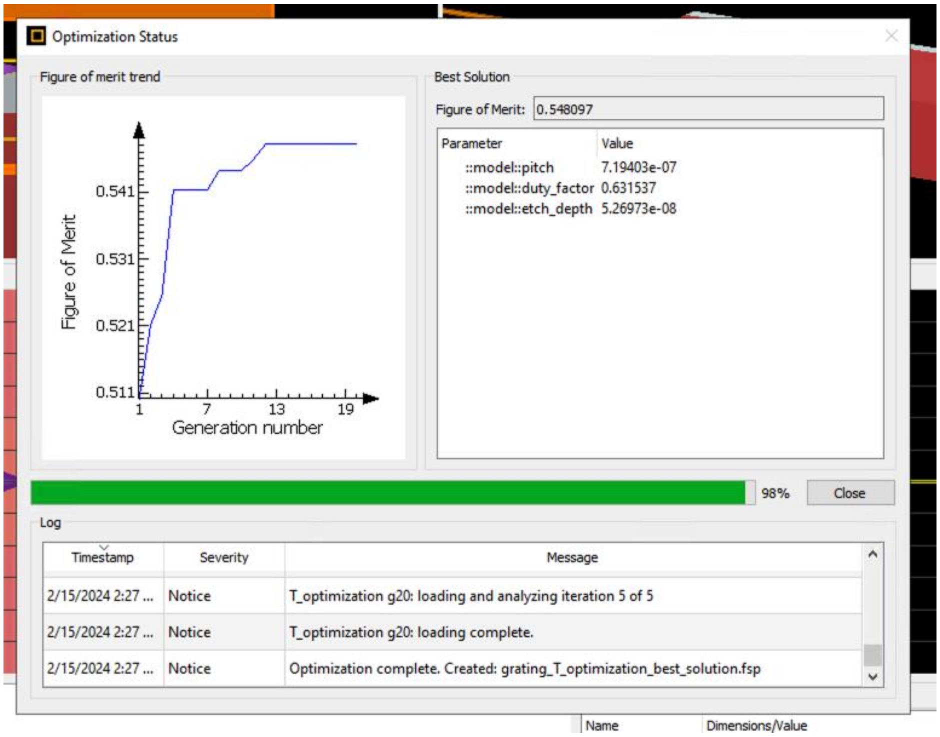
3. In grating design, some of the common 'knobs' are the pitch, duty factor, and etch depth. Add these three variables to our parameter list – be cognizant of the variable *type*. The *Min* and *Max* for each variable is also important. The optimal parameter set should be constrained within these bounds, but we shouldn't make them too large as to settle on a local maximum. This may take some attempts to get correct.



4. As with the sweep, add our transmission result as the *Figure of merit*. This will be the object that is being optimized.



5. Run the optimization. Lumerical will generate 5 unique simulation files, each randomly selected from our parameter min/max ranges. After running these 5, the FOM will be analyzed and a new generation will be made, using trends from the previous generation. This will repeat until a solution is converged.



6. Load the best solution and examine the different monitors.

Follow-up Question:

1. In the previous example, we only optimized the upward radiation of the grating. However, for a practical grating coupler, it is essential to consider the coupling from the grating to the fiber mode. To efficiently couple light into an optical fiber, we need to optimize the coupling efficiency into the fiber mode, which requires simulating the fiber and optimizing the overlap between the grating output and the fiber mode.

   Please use Lumerical's scripting, analysis, and optimization tools to set up this simulation. Design a uniform grating coupler and optimize its transmission into a single-mode fiber.

   What changes need to be made to the current setup? What should we pay attention to?

   Note: You may refer to the uploaded file ***grating_coupler_2D_fiber.fsp*** or consult the design guidelines on the Lumerical website https://optics.ansys.com/hc/en-us/articles/360042305334-Grating-coupler.

Key considerations for this case:

- Include the fiber structure in the simulation

It is recommended to build the fiber using a *structure group*, as this allows you to easily rotate it to match the desired coupling angle.

- Use FDTD *ports* instead of *monitors*

Ports are preferred because they can compute the mode coupling coefficients more easily. Additionally, in Lumerical, *ports* can be easily rotated while *monitors* cannot — this is important since the fiber connected to the grating coupler is typically tilted with respect to the vertical axis

- Use $|S|^2$ (power coupling) instead of T (transmission).

When evaluating coupling into a specific fiber mode, examine ***abs(S)^2***, which represents the fraction of power coupled from the source mode to the port mode, rather than using the transmission value *T* as in the current setup.

Reference

[1] Thevenot, Axel. "Particle Swarm Optimization (PSO) Visually Explained." *Medium*, 21 Dec. 2020, https://medium.com/data-science/particle-swarm-optimization-visually-explained-46289eeb2e14

[2] "Grating Coupler." *Ansys Optics*, Ansys, https://optics.ansys.com/hc/en-us/articles/360042305334-Grating-coupler.