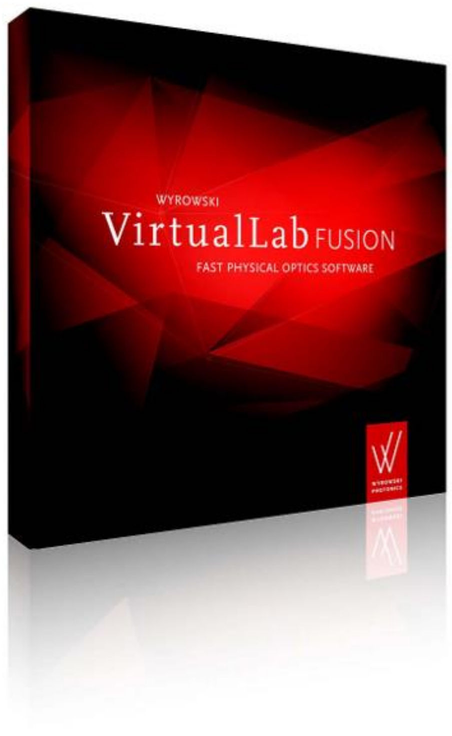
Cross-Platform Optical Modeling and Design with VirtualLab Fusion and MATLAB

Abstract



VirtualLab Fusion allows external access to its solvers. This is helpful if data processing or optimization tools other than those of VirtualLab should be used. Via the standard batch mode, we demonstrate how to use MATLAB to trigger VirtualLab in the background to run optical simulations and output their results which can then be further processed and visualized with MATLAB's capabilities. As example rigorous grating analyses, parametric scanning and an optimization are shown.

Workflow Overview

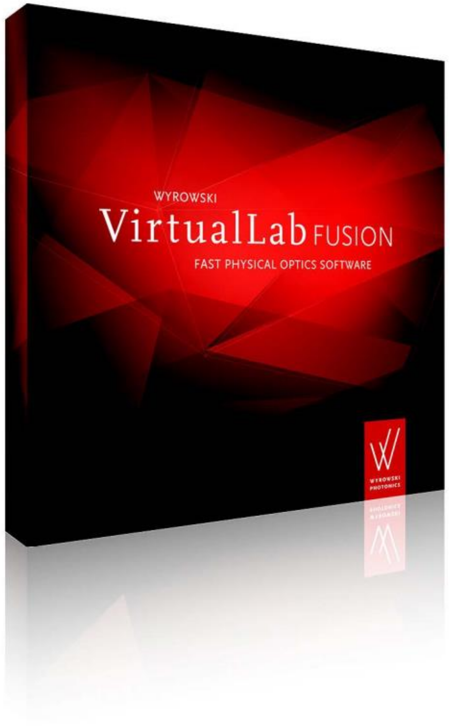
MATLAB
- interactive access to batch mode files
- external mathematical functions and tools

Batch Mode Files
- execution of simulations
- optical parameters and simulation result storage

VirtualLab Fusion
- optical setup definition
- kernel simulation engine

MATLAB

batch file, xml files, ...

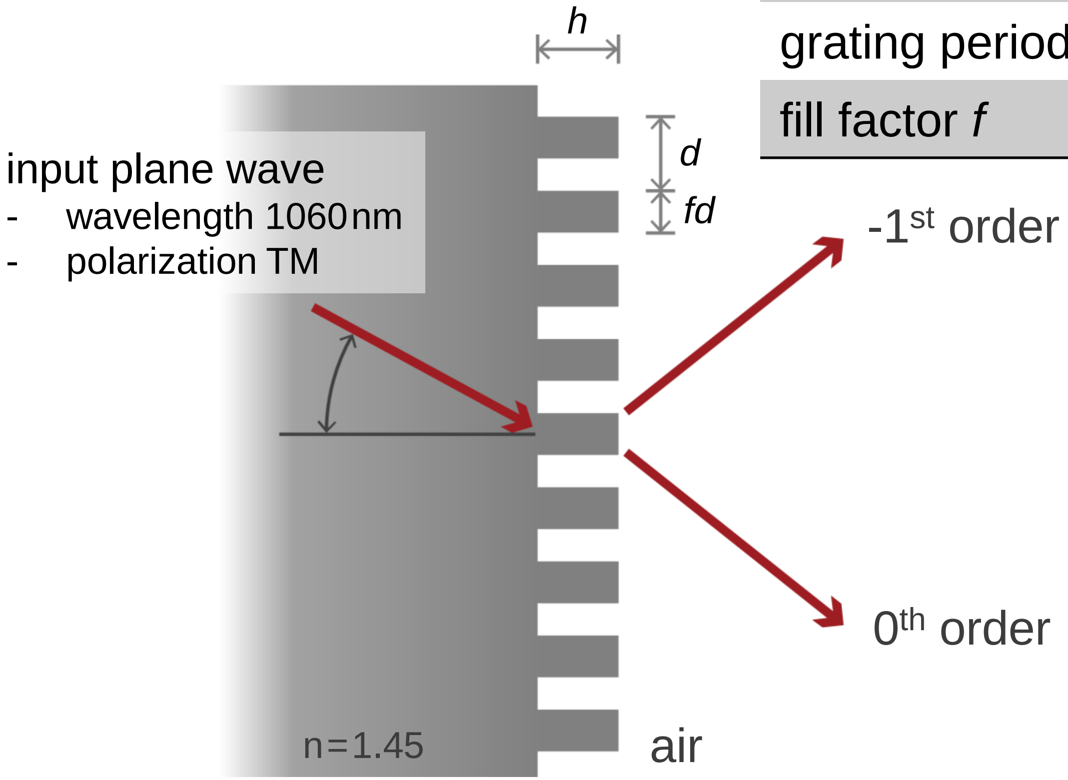


cross-platform simulation

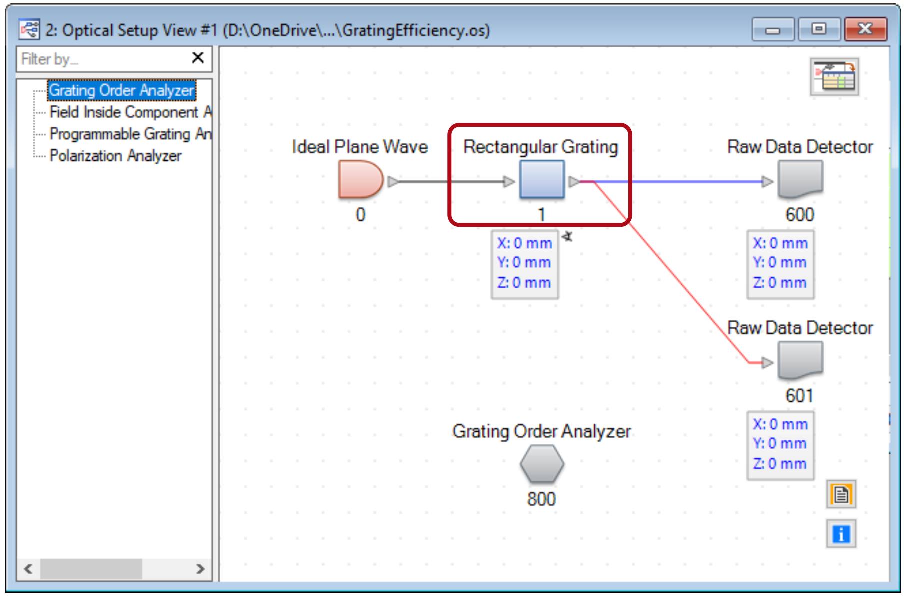
Define Optical Setup in VirtualLab Fusion

initial grating parameters

Parameter	Value
grating depth *h*	1.85 µm
grating period *d*	1060 nm
fill factor *f*	50 %

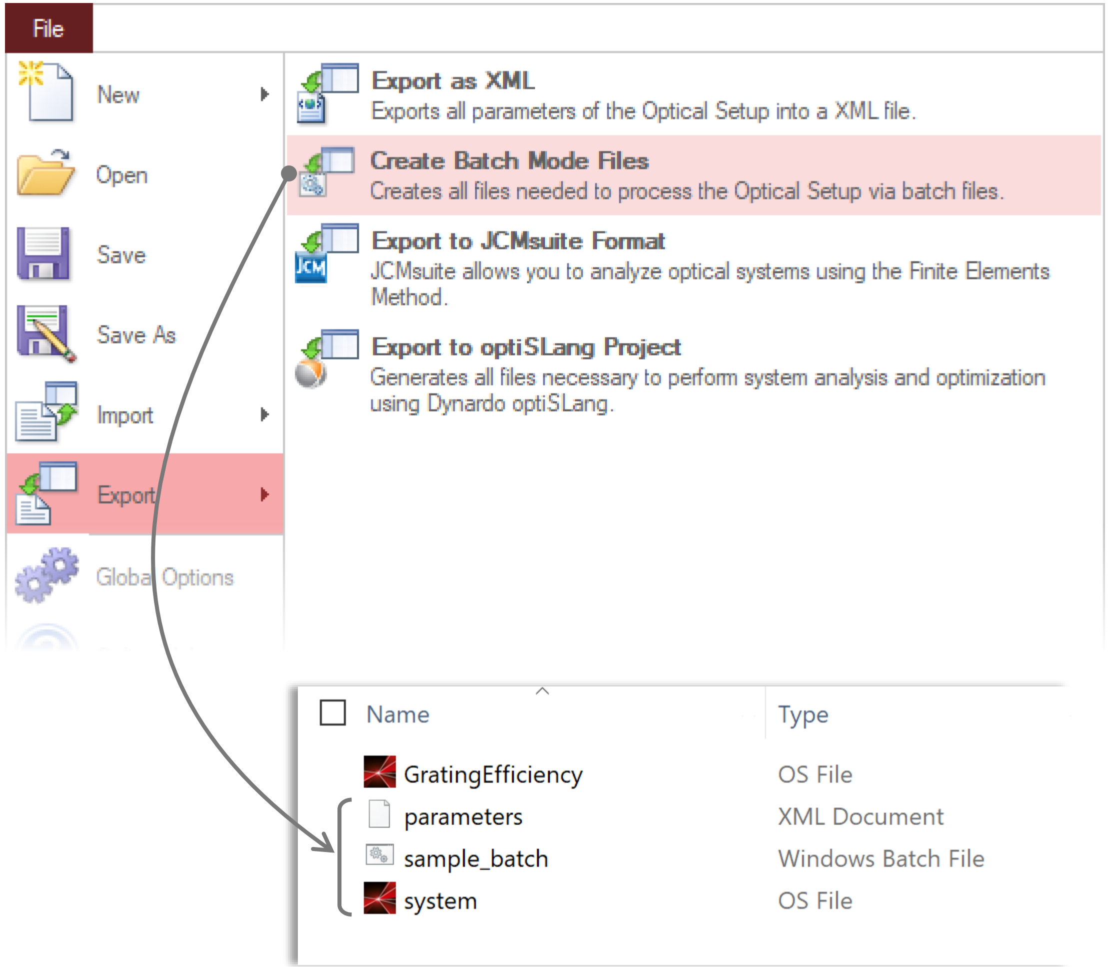


corresponding optical setup generated in VirtualLab



Create Batch Mode Files

- First we create batch mode files for a selected optical setup.
- In the selected folder, three new files are generated
  1. parameters.xml
     xml file containing all parameters of the optical setup from VirtualLab
  2. sample_batch.bat
     batch file containing commands intended to be executed
  3. system.os
     os file (VirtualLab file format) containing the original optical setup



Batch File Content

The batch file can be opened with any editor like program.

After the generation of the batch file, there will be as many commands listed to trigger a VirtualLab Fusion simulation as simulation engines are available in the optical setup document, e.g.

- Field Tracing
- Classic Field Tracing
- Ray Tracing
- Ray Tracing System Analyzer

Typically not all type of simulations are required and also not all optional arguments, e.g. the generation of a subfolder where the results are input.

The command looks like the following:

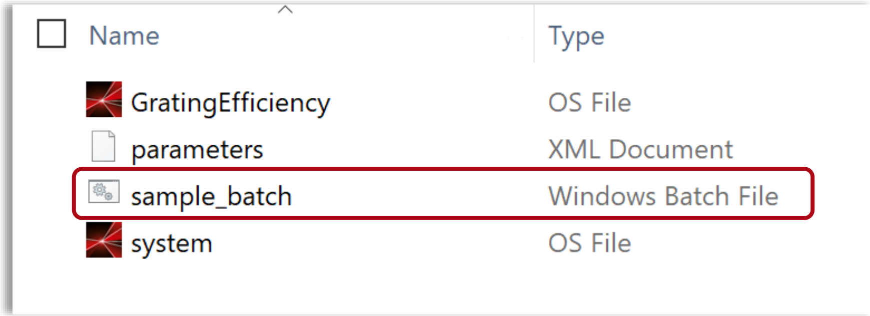
ARGUMENT(S)	DESCRIPTION
-performLPD {1}	The mandatory argument `-performLPD` must be followed by the path and file name of the Optical Setup to be simulated.
{2}	The output folder. Results are written into a `results.xml` file. Complex documents which cannot be saved into this XML file are stored as separate documents, the `results.xml` file then contains only a reference to that file. If warnings or errors occur during the simulation, they are written into a `ProcessingInfo.log` file. (If *Pop up Error Messages* or *Pop up Warning Messages* is activated in the Global Options dialog (↪Sec. 6.22), the corresponding messages are also shown in a message box.)
-parameters {3}	With this optional argument you can specify a XML file with parameter values. These values are then used for the simulation instead of the original parameter values. You can use File > Export > Create Batch Mode Files to create a sample XML file named `parameters.xml` with the correct format.
-engine {4}	With this optional argument you can specify the simulation engine to be used. “0” refers to Classic Field Tracing, “1” to Field Tracing, “2” to Ray Tracing, and “4” to Ray Tracing System Analyzer. Other numbers refer to the index of the analyzer to be used for the simulation. If this parameter is not specified, the *Default Simulation Engine* from the Global Options dialog (↪Sec. 6.5) is used. For Laser Resonator Optical Setups always the Eigenmode Analyzer is used.
-subfolder	If this optional parameter is specified, a subfolder in the output folder `{2}` is generated where the result and logging files are stored. In this way consecutive calls of the `virtuallab.exe` do not overwrite already calculated results. The name of the subfolder is `<Name of simulation engine> (<Date and Time>)`.

```
virtuallab.exe -performLPD {1} {2} [-parameters {3}] [-engine {4}] [-subfolder]
```

Modify Batch File

Open batch file (e.g. with an editor)

1. choose simulation engine
   (in this example only the Grating Order Analyzer is used)
2. delete the output option
   (the presented example works without subfolder)




```
"%VirtualLab_AppDir%\VirtualLab.exe" -performLPD "C:\VLF-Python\system.os" "C:\VLF-Python" -parameters "C:\VLF-Python\parameters.xml" -engine 2 -subfolder & REM Classic Field Tracing
"%VirtualLab_AppDir%\VirtualLab.exe" -performLPD "C:\VLF-Python\system.os" "C:\VLF-Python" -parameters "C:\VLF-Python\parameters.xml" -engine 800 -subfolder & REM Grating Order Analyzer
```

[original batch file]

1. delete the line for Classic Field Tracing →

```
-engine 2 -subfolder & REM Classic Field Tracing
-engine 800 -subfolder & REM Grating Order Analyzer
```

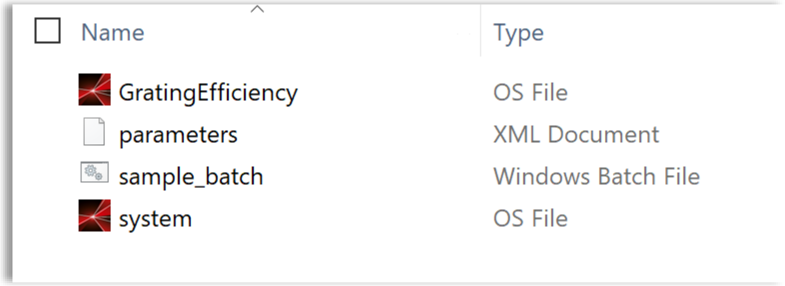
2. delete subfolder option

[modified batch file]

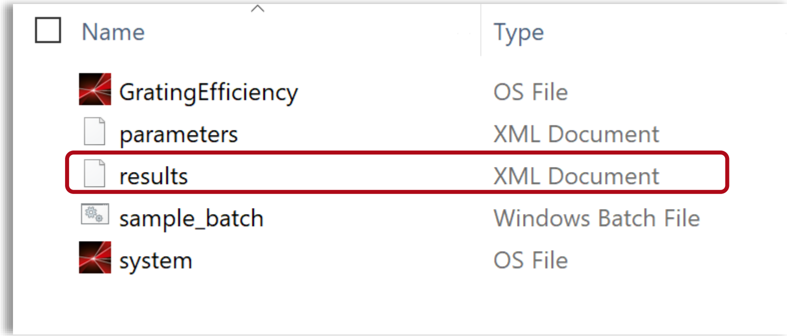
```
-engine 800 & REM Grating Order Analyzer
```

Execute Simulation Using Batch File

- It is recommended to execute the batch file first (e.g. by double click in the MS Explorer window), as a pre-check for the complete workflow.
- After execution, a new file is generated
  - results
    (xml file containing the result values)
- One may also open the result.xml file to check the result values.



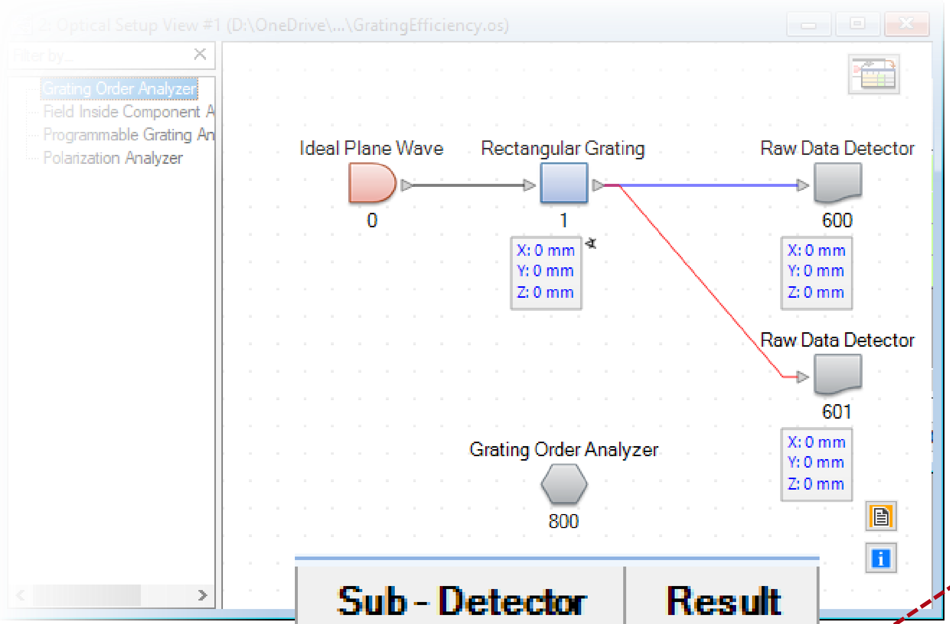
before executing batch file



after executing batch file

Checking Simulation Results Generated by Batch File

- Results in VirtualLab Fusion



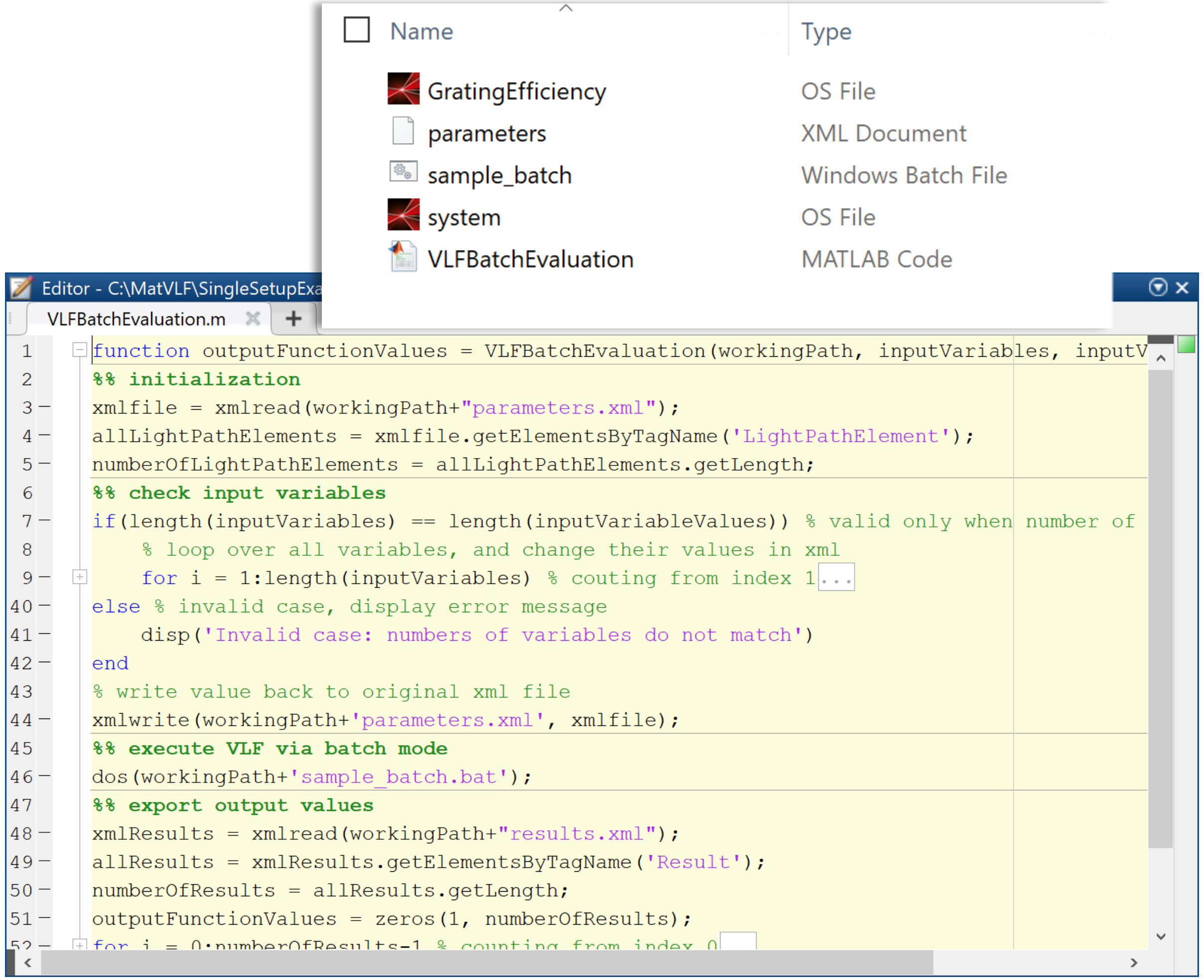
Sub - Detector	Result
Efficiency T[-1; 0]	87.41 %
Efficiency T[0; 0]	10.331 %
Efficiency T[+1; 0]	0 %

- Results in xml file (can be viewed e.g. in simpled text editor or internet browser)


```
<?xml version="1.0" encoding="UTF-8"?>
- <Detector_Results Engine="Grating Order Analyzer">
    <VLVersion Version="2020.2.2.22"/>
  - <Detector_Result Type="List of Physical Values" Name="“Grating
    Order Analyzer” (# 800) (Results for Individual Orders)">
    - <Result Index="0">
        <Name>Efficiency T[-1; 0]</Name>
        <Value>87.409800037125478</Value>
        <Unit>%</Unit>
      </Result>
    - <Result Index="1">
        <Name>Efficiency T[0; 0]</Name>
        <Value>10.330826275349573</Value>
        <Unit>%</Unit>
      </Result>
    - <Result Index="2">
        <Name>Efficiency T[+1; 0]</Name>
        <Value>0</Value>
        <Unit>%</Unit>
      </Result>
    </Detector_Result>
</Detector_Results>
```

Execute Simulation Using MATLAB (via Batch)

- A basic MATLAB function has been prepared for executing the batch file and interacting the related xml files.
- Copy **"VLFBatchEvaluation.m"** file directly to the previous working.



Execute Simulation Using MATLAB (via Batch)

In this example, one can execute the MATLAB function by using the following commands

```
>> workingPath = 'C:\...\SingleSetupExample\';
>> inputVariables = {'Rectangular Grating\Modulation Depth'};
>> inputVariableValues = 1.85e-6;
```

← your working directory

← with this specification, the provided MATLAB code is able to find and set the desired parameter

← values are given in SI units (meters)

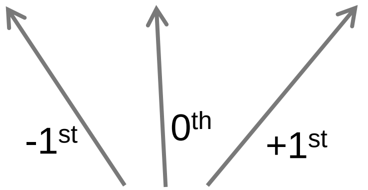
```
>> VLFBatchEvaluation(workingPath, inputVariables, inputVariableValues)
```

```
>> VLFBatchEvaluation(workingPath, inputVariables, inputVariableValues)

C:\MatVLF\SingleSetupExample>"C:\Program Files\Wyrowski Photonics\VirtualLa

ans =

   87.4098   10.3308         0
```



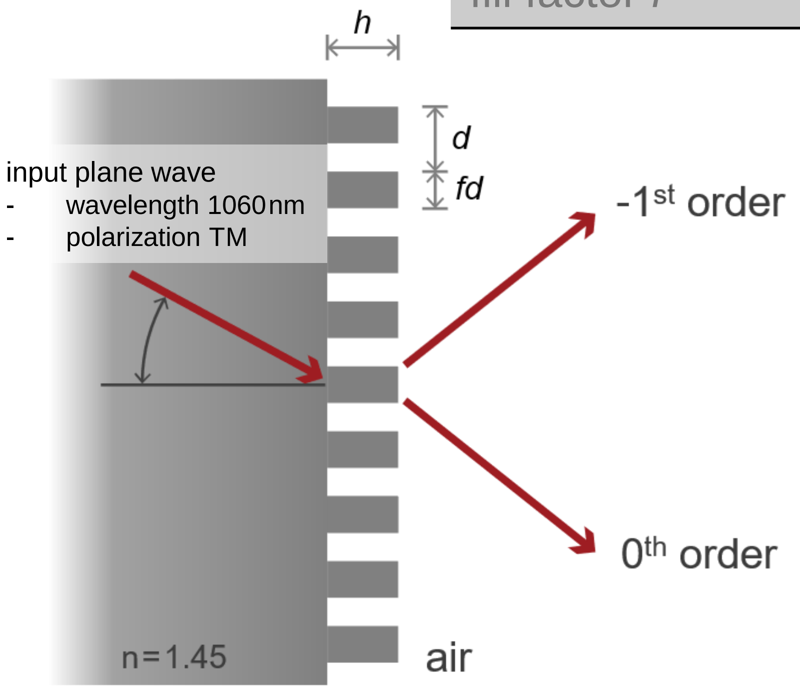
diffraction efficiencies (%)

Parameter Scanning – Varying Single Parameter

- The basic MATLAB file can be used as a sub-function in another MATLAB file as well.
- As an example, we demonstrate how to scan a selected parameter in the optical setup and to check the influence on the result.
- In this example the grating depth is varied, and the transmitted diffraction efficiency of the -1st order is evaluated.

grating parameters

Parameter	Value
grating depth *h*	**[0.1; 10.0] µm**
grating period *d*	1060 nm
fill factor *f*	50 %

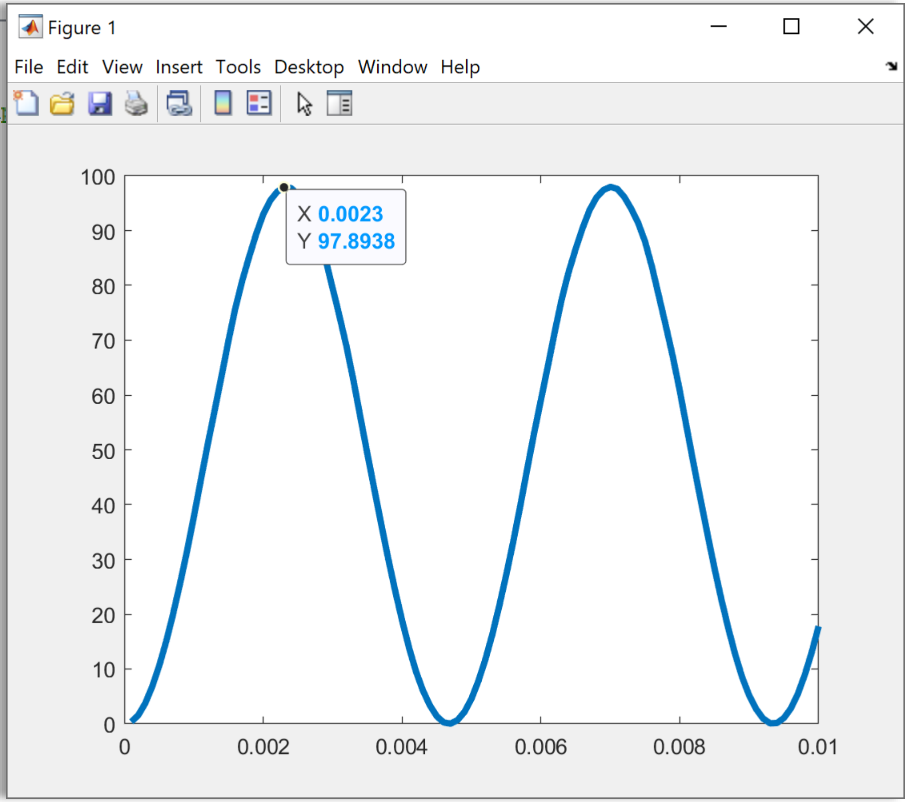


Parameter Scanning – Varying Single Parameter

To use the example file, directly copy the MATLAB file ParameterScan1D.m into the working folder, adjust the working path, and then execute it.

ParameterScan1D.m

```
% define parameters
workingPath = 'C:\MatVLF\SingleSetupExample\';
inputVariables = {'Rectangular Grating\Modulation Depth'}; % 'Optical Setu
% define varying range
gratingDepthMax = 10e-6; % given in meters
gratingDepthMin = 0.1e-6; % given in meters
stepNumber = 100;
stepSize = (gratingDepthMax - gratingDepthMin) / (stepNumber - 1);
efficiencies = zeros(1, stepNumber);
% loop for input variables
for i = 1:stepNumber
    % current value of variable
    gratingDepth = gratingDepthMin +  (i-1) * stepSize;
    % call function
    outputFunctionValues = VLFBatchEvaluation(workingPath, inputVariables,
    % get the function value under investigation
    minusFirstEfficiency = outputFunctionValues(1);
    efficiencies(i) = minusFirstEfficiency;
end
% plot the results
x = gratingDepthMin : stepSize : gratingDepthMax;
plot(x, efficiencies)
```

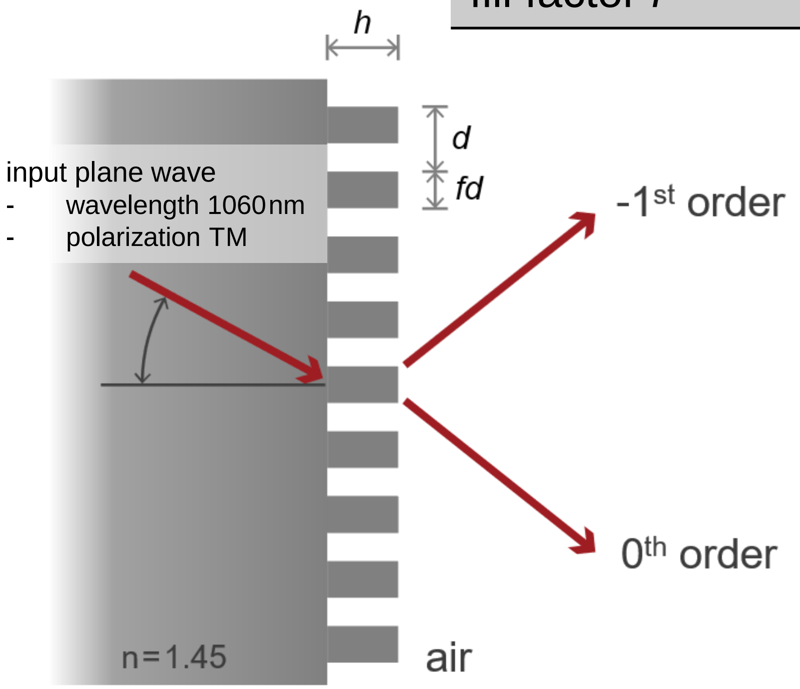


Parameter Scanning – Varying Multiple Parameters

- The basic MATLAB file can be applied in a flexible way.
- For example, one can vary multiple variables and make a multi-dimensional scan over the parameter space.
- In this example, both the grating depth and the fill factor are varied, and again the diffraction efficiency of the -1st order is under investigation.

grating parameters

Parameter	Value
grating depth *h*	**[0.1; 10.0] µm**
grating period *d*	1060 nm
fill factor *f*	**[20; 80] %**

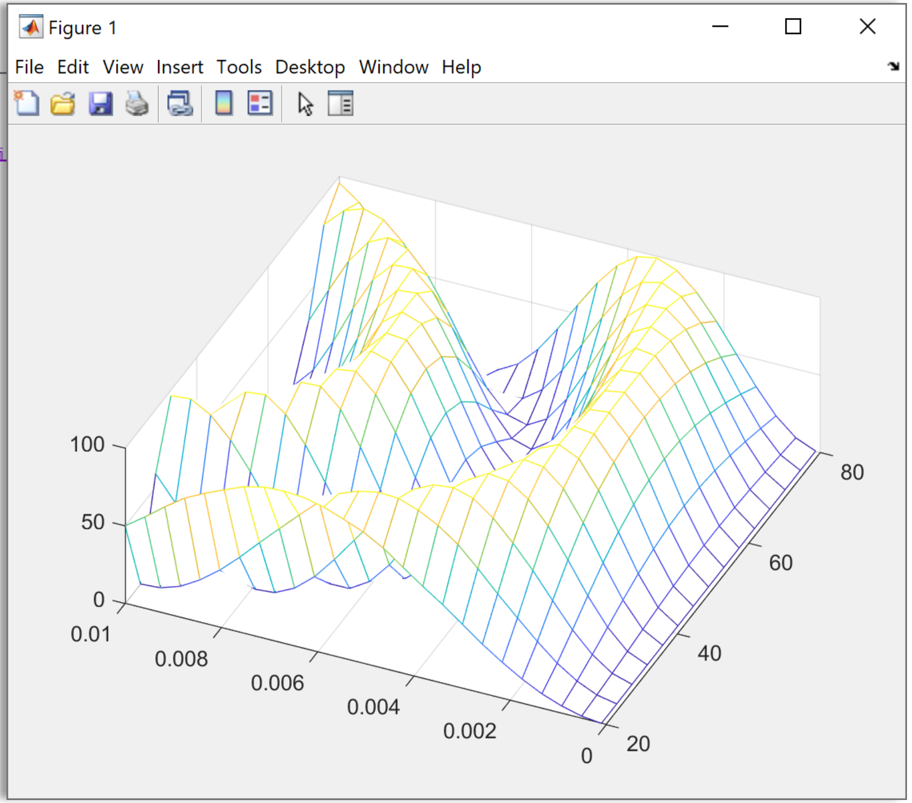


Parameter Scanning – Varying Multiple Parameters

To use the example file, directly copy the MATLAB file ParameterScan2D into the working folder, adjust the working path, and then execute it.

ParameterScan2D.m

```
% define parameters
workingPath = 'C:\MatVLF\SingleSetupExample\';
inputVariables = {'Rectangular Grating\Modulation Depth', 'Rectangular Grating\Relative Sli
% define varying range
gratingDepthMax = 10e-6; % given in meters
gratingDepthMin = 0.1-6; % given in meters
stepNumberDepth = 25;
stepSizeDepth = (gratingDepthMax - gratingDepthMin) / (stepNumberDepth - 1);
slitWidthMax = 80; % given in %
slitWidthMin = 20; % given in %
stepNumberSlit = 15;
stepSizeSlit = (slitWidthMax - slitWidthMin) / (stepNumberSlit - 1);
efficiencies = zeros(stepNumberDepth, stepNumberSlit);
% loop for input variables
for i = 1:stepNumberDepth
    % current value of grating depth
    gratingDepth = gratingDepthMin +  (i-1) * stepSizeDepth;
    for j = 1:stepNumberSlit
        % current value of slit with
        slitWidth = slitWidthMin + (j-1)* stepSizeSlit;
        inputVariableValues = [gratingDepth, slitWidth];
        % call function
```

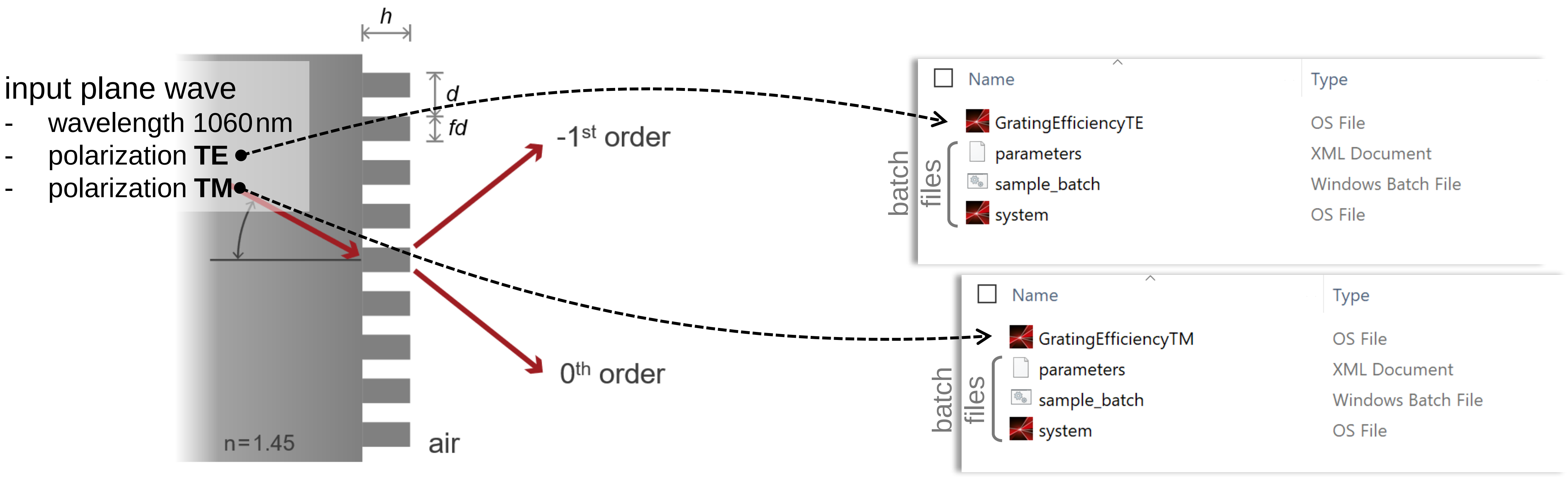


Multiple Configuration Simulation

grating parameters

Parameter	Value
grating depth *h*	**[0.1; 10.0] µm**
grating period *d*	1060 nm
fill factor *f*	50 %

- Generate optical setups for both **TE and TM polarization** (sample files are given in separate folders).
- Then, create batch mode files respectively.



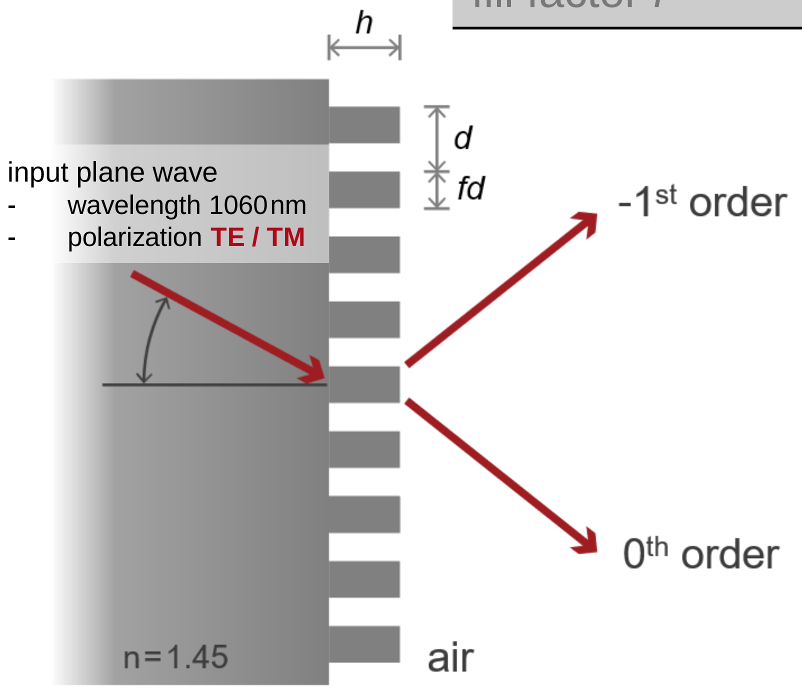
Varying Single Parameter in Multiple Configurations

- As an example, we demonstrate how to vary the grating depth in both TE and TM configurations.
- The diffraction efficiency of the -1^{st} order for both polarizations, as well as their average value are under investigation.

- For this, another exemplary MATLAB file is provided: **"ParameterScan1DTETM.m"**
- This access the two subfolders with TE/TM configured files and triggers the simulations with varied parameter.

grating parameters

Parameter	Value
grating depth *h*	**[0.1; 10.0] µm**
grating period *d*	1060 nm
fill factor *f*	50 %

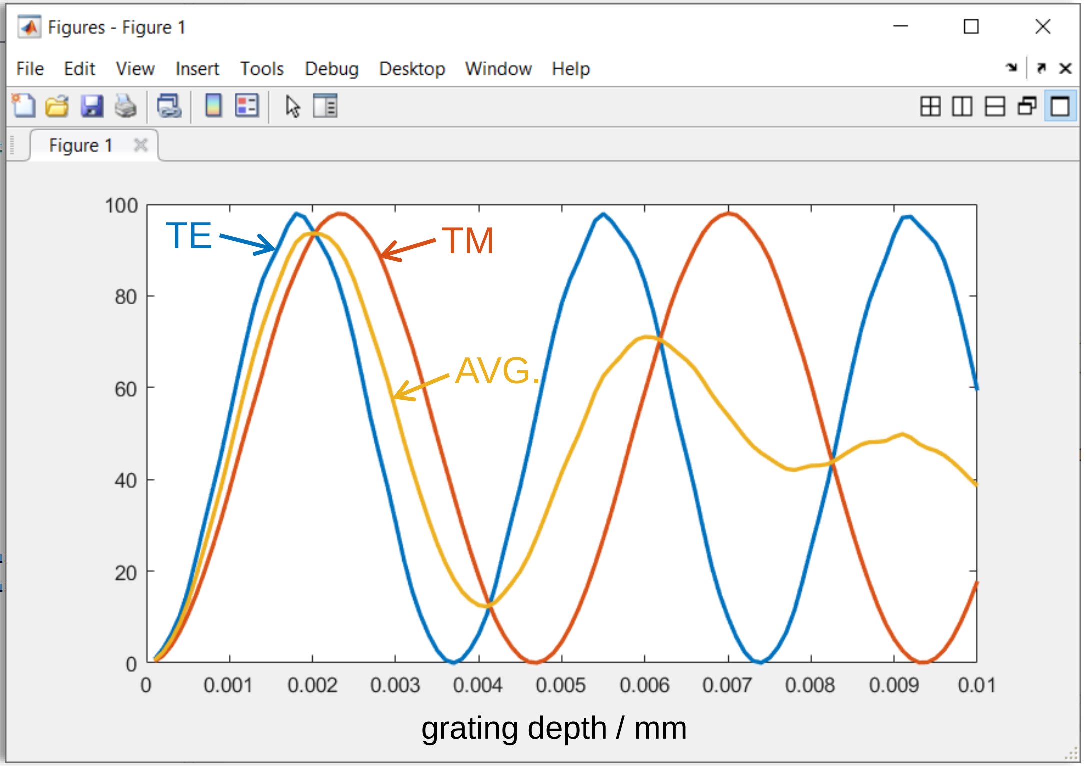


Varying Single Parameter in Multiple Configurations

Directly copy the MATLAB file **"ParameterScan1DTETM.m"** into the working folder, adjust the working paths, and then execute it.

ParameterScan1DTETM.m

```
% define parameters
workingPathTE = 'C:\MatVLF\MultipleConfigExample\TE\';
workingPathTM = 'C:\MatVLF\MultipleConfigExample\TM\';
inputVariables = {'Rectangular Grating\Modulation Depth'}; % 'Optical Setup Element
% define varying range
gratingDepthMax = 10e-6; % given in meters
gratingDepthMin = 0.1e-6; % given in meters
stepNumber = 100;
stepSize = (gratingDepthMax - gratingDepthMin) / (stepNumber - 1);
efficienciesTE = zeros(1, stepNumber);
efficienciesTM = zeros(1, stepNumber);
efficiencyAVG = zeros(1, stepNumber);
% loop for input variables
for i = 1:stepNumber
    % current value of variable
    gratingDepth = gratingDepthMin +  (i-1) * stepSize;
    % call function
    minusFirstEfficiencyTE = VLFBatchEvaluation_SingleOutput(workingPathTE, inputVa
    minusFirstEfficiencyTM = VLFBatchEvaluation_SingleOutput(workingPathTM, inputVa
    efficienciesTE(i) = minusFirstEfficiencyTE;
    efficienciesTM(i) = minusFirstEfficiencyTM;
    efficiencyAVG(i) = 0.5 * (minusFirstEfficiencyTE + minusFirstEfficiencyTM);
end
% plot the results
x = gratingDepthMin : stepSize : gratingDepthMax;
plot(x, efficienciesTE, x, efficienciesTM, x, efficiencyAVG)
```



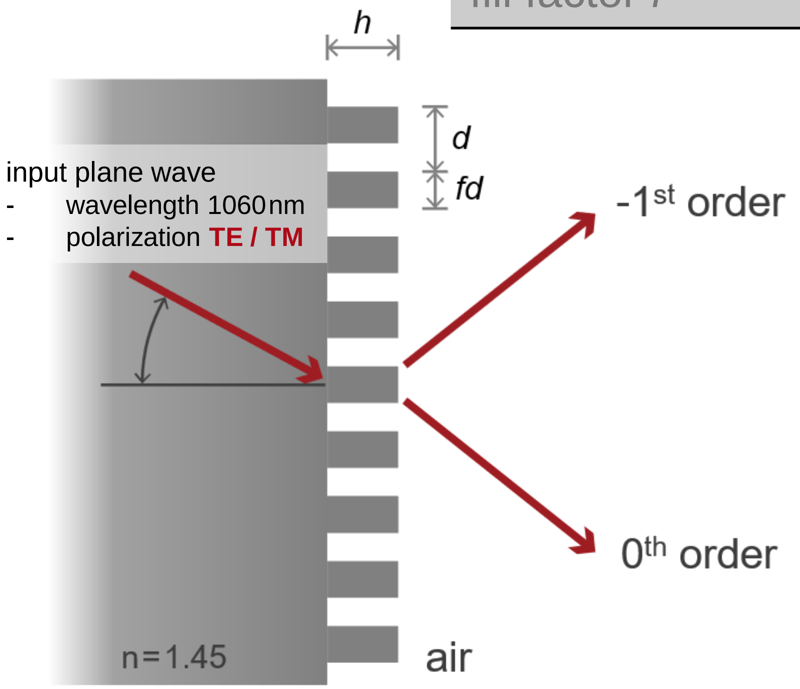
Parametric Optimization with Multiple Configurations

- Based on the previous example, instead of scanning, we demonstrate how to optimize selected parameters with MATLAB in-built minimization function.
- As an example, the grating depth is set as the variable and the average efficiency of both TE and TM polarizations is to be maximized.
- For this, a further MATLAB file is provided: **"ParametricOptimization1D.m"**

grating parameters

Parameter	Value
grating depth *h*	? µm
grating period *d*	1060 nm
fill factor *f*	50 %

to be optimized → grating depth *h*



Parametric Optimization with Multiple Configurations

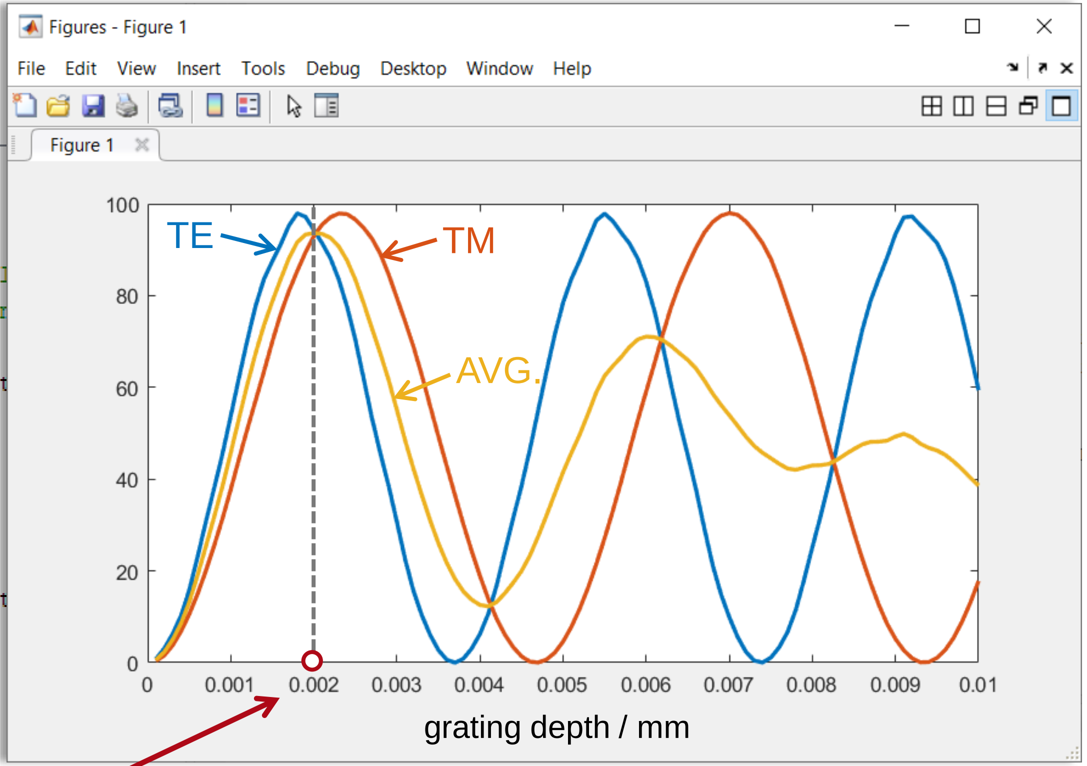
Directly copy the MATLAB file **"ParametricOptimization1D.m"** into the working folder, adjust the working paths, set a varying range, and then execute it.

ParametricOptimization1D.m

```
% define parameters (constant)
workingPathTE = 'C:\MatVLF\MultipleConfigExample\TE\';
workingPathTM = 'C:\MatVLF\MultipleConfigExample\TM\';
inputVariables = {'Rectangular Grating\Modulation Depth'}; % 'Optical
% define single-input function as the merit function for optimizatior
maxEfficiency = 100; % given in percentage
meritFunc =@(gratingDepth) 100 - 0.5*(VLFBatchEvaluation_SingleOutput

% define varying range
gratingDepthMax = 8e-6; % given in meters
gratingDepthMin = 0.1e-6; % given in meters
% optimization of grating depth
[gratingDepth, meritFunc] = fminbnd( meritFunc, gratingDepthMin, grat

```



calculated grating depth is 2 μm

Document Information

title	Cross-Platform Optical Modeling and Design with VirtualLab Fusion and MATLAB
document code	CPF.0001
version	2.0
toolbox(es)	(depending on situation; Grating Toolbox used for this example)
– VLF version – MATLAB version	– 7.5.0.158 – version R2019a used for all examples
category	Feature Use Case
further reading	- Cross-Platform Optical Modeling and Design with VirtualLab Fusion and Python