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# RAWDOG

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User Manual

2014

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# Introduction

RawDog (Rigorous Analysis of Wave Diffraction on Gratings) is a MATLAB application providing calculations for reflection and transmission coefficients (diffraction efficiencies) of periodic structures (such as optical gratings, photonic crystals, etc.) based on the Rigorous Coupled Wave Analysis (RCWA).

Developer: Gergely Kajtár – for further info visit: <http://rawdoggapp.weebly.com/about>

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Website: <http://rawdoggapp.weebly.com>

## How to launch RawDog?

First of all, you will need MATLAB (<http://www.mathworks.com/products/matlab>) installed on your computer or, if you don't have Matlab, Windows 64 bit OS. If this requirement is met, there are two possibilities to launch RawDog:

### *Launch RawDog as p-file (recommended)*

1. Download file *RawDog.zip* from website: <http://rawdoggapp.weebly.com/download>
2. Extract folder *RawDog-MATLAB* from *RawDog.zip* to a location.
3. Set extracted folder *RawDog-MATLAB* as *Current folder* or add it to MATLAB path (Set *Path*) **with subfolders**.
4. Type *RAWDOG* into MATLAB's Command Window, press Enter.

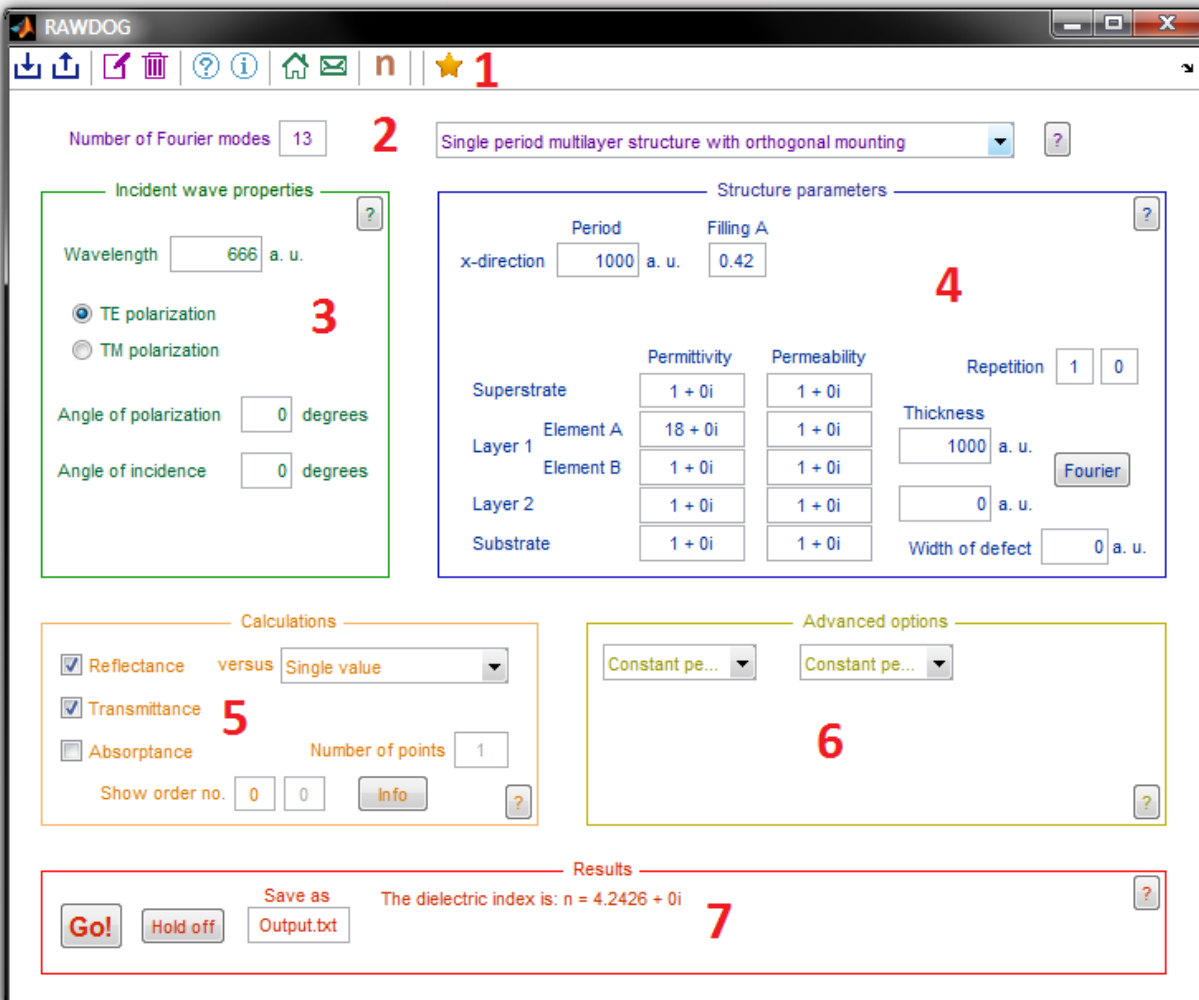
### *Launch RawDog as Windows executable – use this only if you don't have MATLAB installed on your PC*

1. Download file *RawDog.zip* from website: <http://rawdoggapp.weebly.com/download>
2. Extract folder *RawDog-Windows 64bit* from *RawDog.zip* to a location.
3. Open *RawDog.exe* from the extracted folder.
4. You will need **MCR version 2014a** for Windows 64 bit installed on your PC, download it from: <http://www.mathworks.com/products/compiler/mcr/index.html>

In case of any problem with the installation, do not hesitate to contact me.

# How to use RawDog?

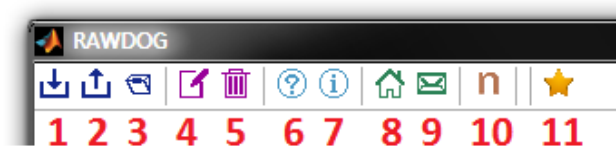
In this paragraph, you will be introduced to the user interface of the program. The interface itself consists of seven panels:



1. Toolbar
2. Structure type selection / Number of modes (purple)
3. Incident wave properties (green)
4. Structure parameters (blue)
5. Calculations (orange)
6. Advanced options (yellow)
7. Results (red)

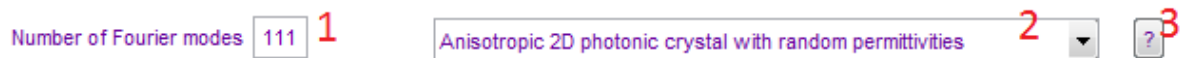
The following paragraphs deal with each panel separately.

## Toolbar

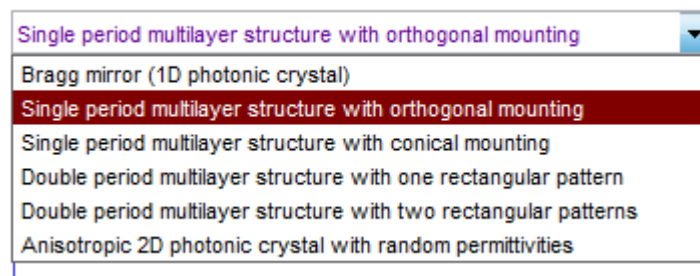


1. Saves parameters from user interface to a text file
2. Loads previously saved parameters from a text file to user interface
3. Opens current folder in file explorer (or in MATLAB)
4. Clears parameters and loads predefined parameters
5. Clears Command Window, Workspace and RawDog output text panel
6. Opens this user manual
7. Shows program version info and contact for the developer
8. Visit RawDog's website
9. Send e-mail to the developer
10. Calculates refractive index
11. Shows info about the full version of RawDog

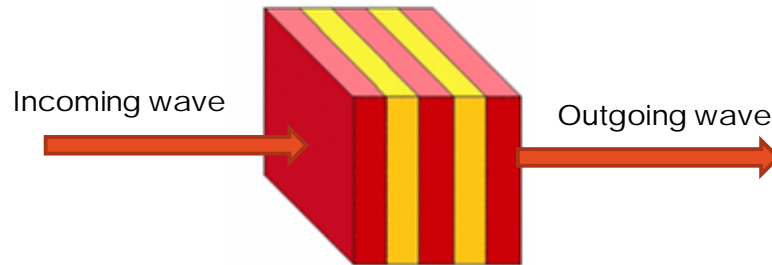
## Structure type selection / Number of modes



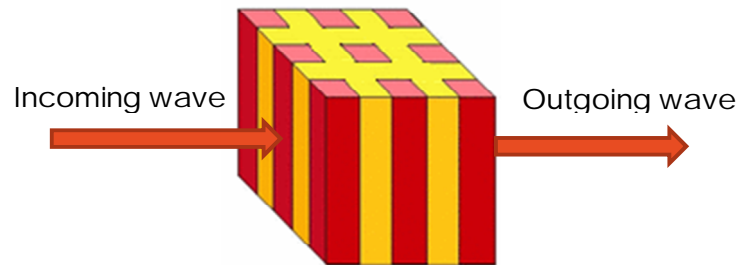
1. Number of Fourier modes represents the only approximation during numerical analysis. The higher this number, the results are more accurate by the cost of computing time and memory used. The total number of Fourier modes is  $2 \times \text{NumberOfFourierModes} + 1$ .
2. There are different structure types you can simulate with RawDog:



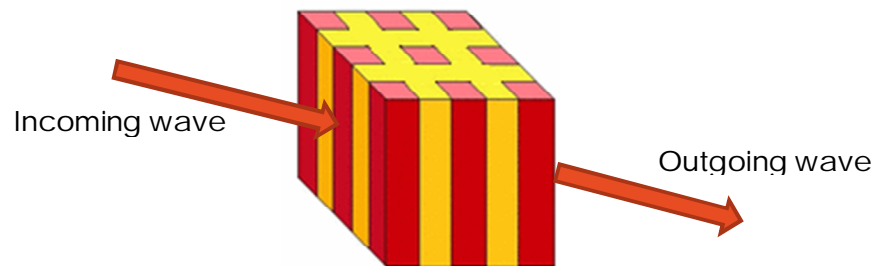
a) Bragg mirror (1D photonic crystal): sandwich of infinite homogeneous layers



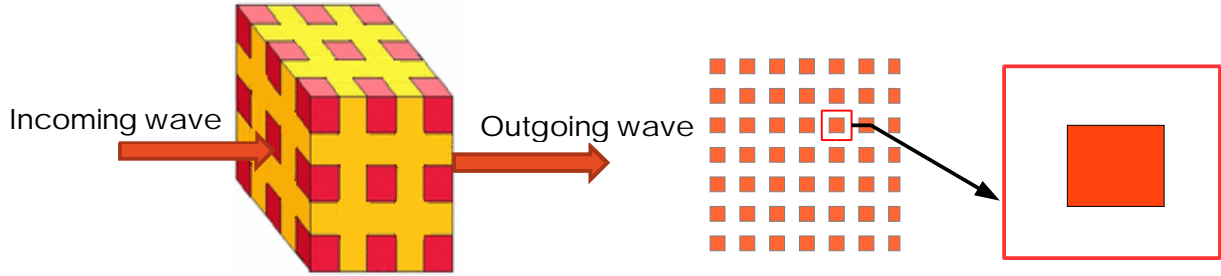
b) Single period multilayer structure with orthogonal mounting: sandwich of lamellar gratings and homogeneous layers, plane of incident wave collinear to the period.



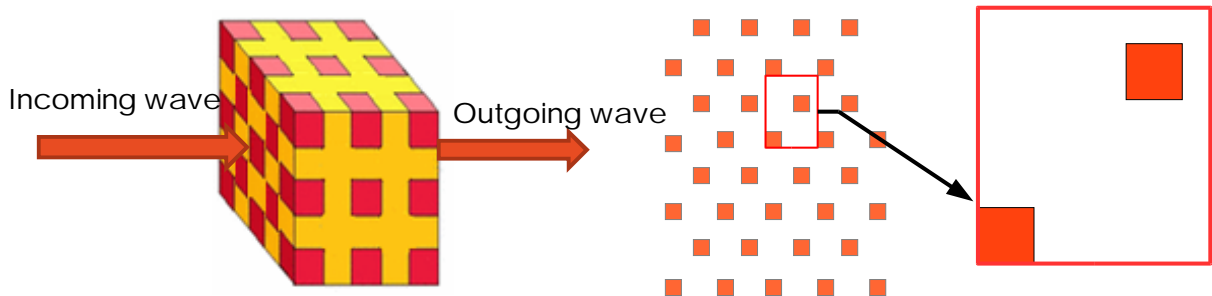
c) Single period multilayer structure with conical mounting: sandwich of lamellar gratings and homogeneous structures, plane of incident wave is not collinear to the period.



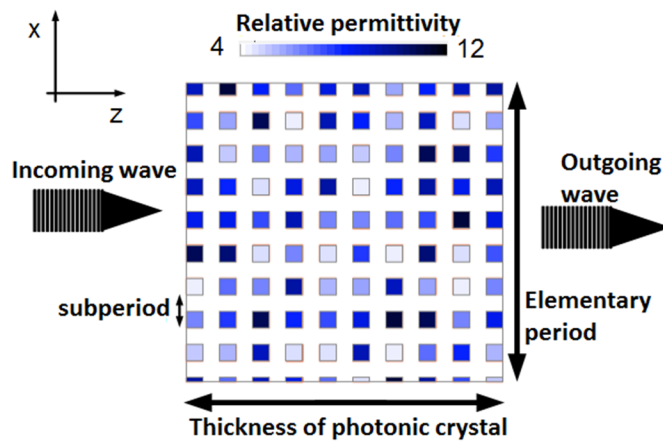
d) Double period multilayer structures with **one** rectangular pattern



e) Double period multilayer structures with **two** rectangular patterns – with this type you can analyze hexagonal structures such as chess board pattern.



f) Anisotropic 2D photonic crystal with random permittivities – with this type you can analyze anisotropic and/or random permittivity photonic crystal. This type of structure is basically the “Single period multilayer structure with orthogonal mounting” but you can set permittivity of rods as anisotropic and/or random (see Section ‘Structure parameters’ for further info) like this:



3. Quick help of the panel

## Incident wave properties

Incident wave properties

Wavelength  a. u.

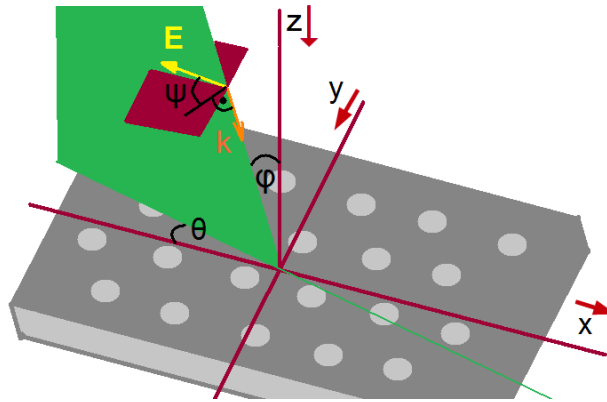
TE polarization  
 TM polarization

Angle of polarization  degrees

Angle of incidence  degrees

Angle of plane of inc.  degrees

1. Quick help of the panel opens as pdf file.
2. Wavelength of the planar incident wave in arbitrary units (except if there is a frequency dependent permittivity or permeability, this case in nanometers: nm)
3. Polarization of electric field vector  $E$  (see Figure below)
4. Angle of polarization:  $\psi$  -  $\psi$  (see below)
5. Angle of incidence:  $\phi$  -  $\phi$  (see below)
6. Angle of plane of incidence:  $\theta$  -  $\theta$  (see below)



## Structure parameters

Structure parameters

x-direction  a. u.

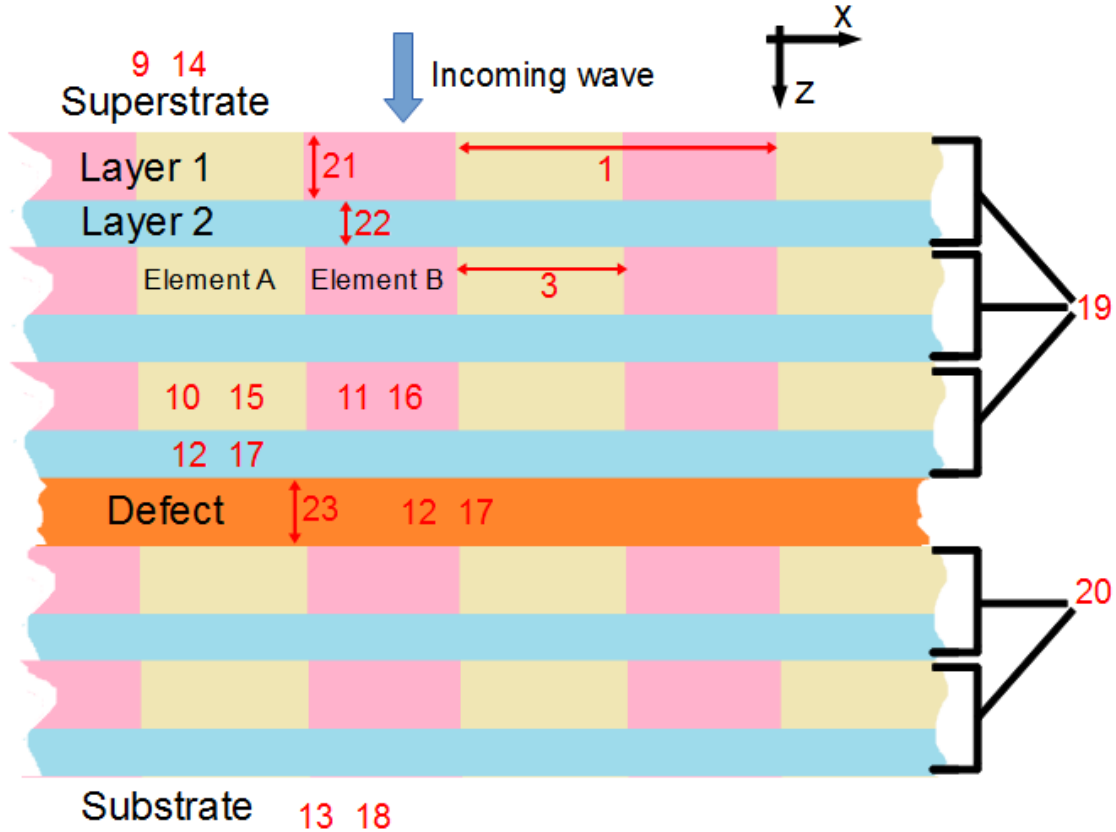
y-direction  a. u.

	Permittivity	Permeability	Repetition
Superstrate	<input type="text" value="1 + 0i"/>	<input type="text" value="1 + 0i"/>	<input type="text" value="1"/> <input type="text" value="0"/>
Layer 1	Element A <input type="text" value="10 + 0i"/>	<input type="text" value="1 + 0i"/>	Thickness <input type="text" value="1000"/> a. u.
	Element B <input type="text" value="1 + 0i"/>	<input type="text" value="1 + 0i"/>	
Layer 2	<input type="text" value="1 + 0i"/>	<input type="text" value="1 + 0i"/>	<input type="text" value="0"/> a. u.
Substrate	<input type="text" value="1 + 0i"/>	<input type="text" value="1 + 0i"/>	Width of defect <input type="text" value="0"/> a. u.

Fourier

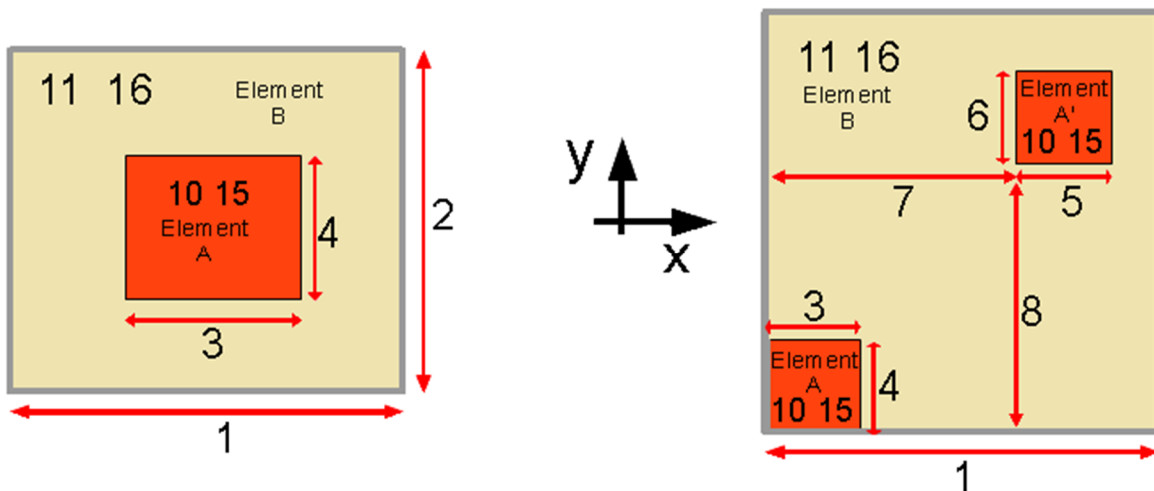


For layers arrangement and single period elements layout refer to this figure:



(the structure above has 'Repetition' 3 above the defect and 2 below the defect)

For double period Layer 1 elements layout (one and two rectangular patterns) refer to this figure:



For anisotropic random permittivity structure elements A and B have permittivity tensor

$$\bar{\epsilon} = \begin{pmatrix} \epsilon_{xx} & \epsilon_{xy} & 0 \\ \epsilon_{xy} & \epsilon_{yy} & 0 \\ 0 & 0 & \epsilon_{zz} \end{pmatrix}$$

where permittivities  $\epsilon_{xx}$ ,  $\epsilon_{xy}$ ,  $\epsilon_{yy}$  are periodic in x-direction,  $\epsilon_{zz}$  is constant.

x-direction  a. u.    Filling A     Nr. of rods     eps\_zz

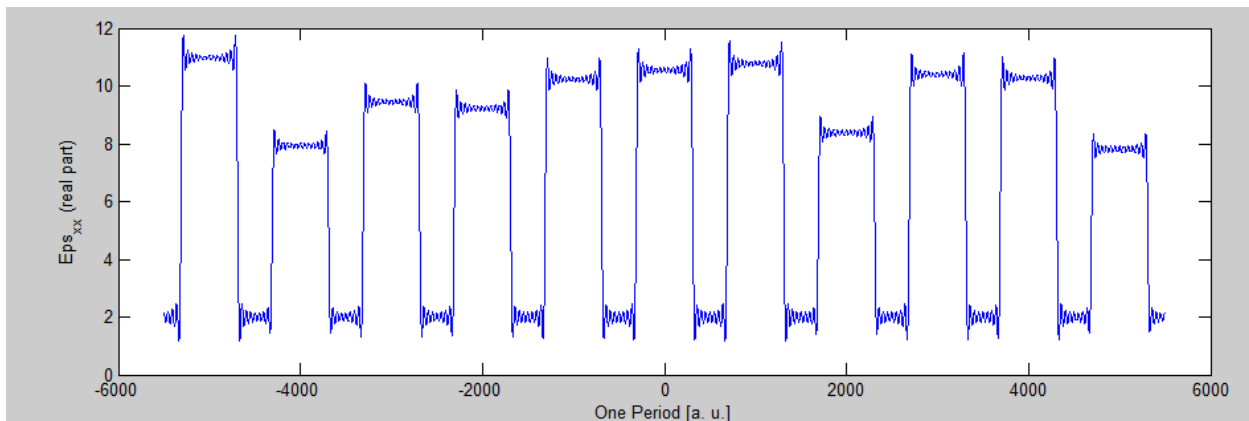
eps\_xx       eps\_xy       eps\_yy

1 2 3    4 5 6    7 8 9

Number of rods (10) extends the subperiod. The total elementary period is consisted of (2\*NumberOfRods + 1) subperiods.

(3), (6) and (9) represent the permittivity of Element B. (1), (4) and (7) represent the permittivity of Element A. (2), (5) and (8) represent the interval where permittivity of Element A is chosen from. If this is zero, the permittivities will not be random but constant

For the numbers above (Nr. of rods = 5, eps\_xx = 7, 5, 2) Fourier expansion of the elementary period looks like the lot below (the permittivity of eps\_xx of Element A is chosen randomly from interval (7, 12 = 7+5), permittivity of Element B is 2):



Clicking on 'Fourier' (24) you will plot the Fourier decomposed function of permittivity of Element A for one elementary period.

Question mark (25) opens the quick help for the panel.

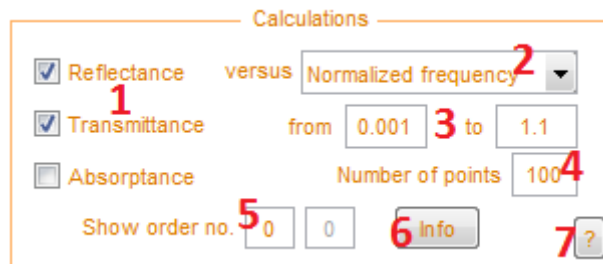
Please note, that number of Fourier modes must be the multiple of number of rods to retain the desired accuracy.

If the structure is repeated (19), each repetition will generate a different random structure.

Notes:

- Filling factors and rod positions are given in respect to the period.
- Periods and thicknesses are in the same units as wavelength.
- You can shorten numbers by using notation of exponents of ten (e. g. 5.25e7 instead of 52500000).
- You can set imaginary permittivity/permeability by typing 'i' after the number (e. g. 3i).

## Calculations



Calculations

Reflectance **1** versus **2** Normalized frequency

Transmittance **3** from 0.001 **3** to 1.1

Absorptance **4** Number of points 100 **4**

Show order no. **5** 0 0 **6** Info **7** ?

1. Reflectance, transmittance and absorptance of the structure. Diffraction efficiency is defined as:

$$\eta = I \frac{\cos \varphi}{\cos \varphi_0}$$

where  $I$  is the intensity of diffracted order,  $\varphi$  is the diffraction angle,  $\varphi_0$  is the angle of incident wave (intensity if incident wave is 1).

2. Plots the selected dependent variables (transmittance, reflectance and absorptance) against independent variables. Independent variables varies for grating structure types:
  - a. Single value – available for all types. Calculates for the given parameters. Results are displayed on the 'Results' panel.
  - b. Wavelength – available for all types. It is given in arbitrary units, except there is a dispersive medium, in this case, it is given in nanometers (nm).
  - c. Normalized frequency – available for all types. It is defined as period/wavelength (for homogenous layers thickness/wavelength).
  - d. Number of modes. Use this to determine convergence of the calculation.
  - e. Different structures – available for random structures. Generates different random structure for each point.
  - f. Frequency vs. angle. Plots against 2 independent variables. There are 90 points for the angle from interval (0, 90).

- The interval of the independent variable. "from" value must be smaller than "to" value. There are certain restriction for individual variables (e. g. angles must be from interval (0, 90) or filling factor must be chosen from interval (0, 1)).
- Set number of points on the given interval to plot. The higher the number of points, the longer the calculation.
- Set which diffraction order you want to plot and save to a text file. For all diffracted orders type ":".
- Shows which diffracted orders are propagating (non-evanescent) waves in the substrate and superstrate for the incident wavelength, also shows diffraction angles.
- Opens quick help of the panel.

## Advanced options

- Here you can set permittivity of Element A non-dispersive (constant) or dispersive (function of wavelength):
  - Constant – relative permittivity is the same for all wavelength
  - Drude’s formula – relative permittivity is given by the equation
 
$$\varepsilon = 1 - \frac{f_p^2}{f(f + iG)}$$
 where  $f_p$  is the plasma frequency,  $G$  is the absorption.
  - Johnson-Christy formula defines relative permittivity as
 
$$\varepsilon = 1 - \frac{f_p^4}{(f^2 + G^2)^2}$$
  - Custom – specify your own dispersion function. Your file must be a data table with three columns. First column must be the wavelength in the same units as your versus wavelength, second column is the real part of relative permittivity, third column is the imaginary part.
- Here you can set permeability of Element A non-dispersive (constant) or dispersive (function of wavelength):
  - Constant – relative permeability is the same for all wavelengths.
  - Pendry’s formula – relative permeability is given by the equation

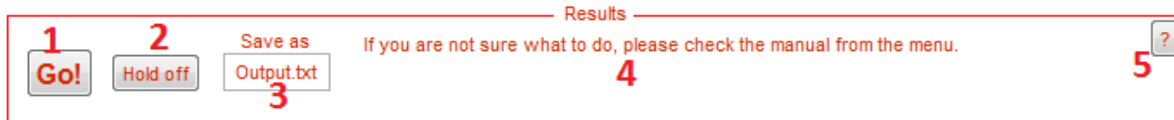
$$\varepsilon = 1 - \frac{Ff^2}{f^2 - f_0^2}$$

where  $F$  is a form factor and  $f_0$  is the resonant frequency.

- c. Custom – specify your own dispersion function. Your file must be a data table with three columns. First column must be the wavelength in the same units as your versus wavelength, second column is the real part of relative permeability, third column is the imaginary part.
3. Plots permittivity/permeability function on interval specified in ‘wavelength’ or ‘normalized frequency’ panel.
4. Opens quick help of the panel.

**Please note wavelength and all thicknesses must be given in nanometers (nm) if the material is dispersive.**

## Results



1. Starts the calculation. Until it finishes, you cannot start another calculation. During calculation a bar is displaying the status of the process.
2. If hold is off, results are plotted in a new figure. If hold is all, results are plotted in the current figure (do not forget to click the existing figure you want the curve plotted to).
3. Name of the file all data are automatically saved to. Data are tab separated. Each row stands for a new independent variable point (wavelength for example). Columns stand for different diffracted orders. First column is the independent variable. For anisotropic structures the total efficiency is saved (TE plus TM polarization), then TE and TM polarizations separately. Reflectance, transmittance and absorptance are saved in separate files. Existing file name will be overwritten!
4. Text output. You will find here various information and results.
5. Quick help of the panel.

## F. A. Q.

Q: Is RawDog a backronym?

A: Yes, it is. :)

Q: I have problems with installation/problem formulation/simulation/etc.

A: *Do not hesitate and send me an e-mail describing your problem.*

Q: What is "hardware identity"?

A: *Hardware identity is a string of alphanumeric characters. You will find your hardware identity after launching the free version of RawDog. This string represents your computer.*

Q: What if I change my computer? Can I transfer the full version of RawDog to another computer?

A: *Unfortunately you cannot. Each full version belongs to a certain computer. You will need to donate again.*

Q: What does "priority support" mean?

A: *Priority support means that you can contact me any time and you will get my response in 24 hours. Also, you can request help for simulating your actual problems and you can request features for RawDog (e. g. add different type of plot).*

Q: I got warning message "Warning: Matrix is close to singular or badly scaled. Results may be inaccurate." What should I do?

A: *You can get this message because of different reasons (e. g. average index of refraction is close to zero). Try to set a slightly different filling factor, angle of incidence, number of modes, etc.*

Q: Results fail to converge for higher Fourier modes.

A: *This usually happens for materials with negative permittivity/permeability. This is not a bug, but the nature of this method. Adding a tiny imaginary part to permittivity/permeability may help.*

Q: What is the difference between the free and full version of RawDog?

A: *Free and full version are practically the same. The only limitation of free version is the results are not saved automatically, you have to do it manually.*

Q: I am not sure how to use RawDog.

A: Try to get help from the manual (click on the question mark on each panel) or hover the pointer over the user interface, so a helping tooltip appears.

Q: There is a new version of my FULL RawDog program. How can I download it?

A: Simply download the newest FREE version of RawDog, it should work. You will get e-mail notification when a new version appears.

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<sup>i</sup> M.G. Moharam and T.K. Gaylord, "Rigorous coupled- wave analysis of planar-grating diffraction," J. Opt. Soc. Am. **71**, 811-818 (1981).