Manual

fiberdesk V4.0

last update 06.11.2011

fiberdesk
nonlinear pulse propagation

1. CONTENTS

2. GENERAL

2.1. SYSTEM REQUIREMENTS

2.1.1. SOFTWARE REQUIREMENTS

FiberDesk V4.0 works stable on the following operating systems:

Microsoft® Windows® XP (SP2) Home Edition / Professional

Microsoft® Windows® Vista

Microsoft® Windows® 7

In addition, because FiberDesk uses the Aladdin™ Protection System, its drivers for the usage of the USB hardware lock are also required.

Please read the installation information.

2.1.2. HARDWARE REQUIREMENTS

Required processor: Intel Pentium or compatible

Required/Recommended RAM: 1 GB or more

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Official web-site: www.fiberdesk.com

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If a scientific citation of fiberdesk is possible use a phrase similar to the following:

[X] simulations done using nonlinear propagation code of FiberDesk, www.fiberdesk.com

More specifically, if the predefined dispersion values are used for any kind of publication, please contact the author (webmaster@fiberdesk.com) for information on copyright and citation.

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3. SOFTWARE INTERFACE

The general graphical layout of **fiberdesk** is shown in Fig. 3.1.

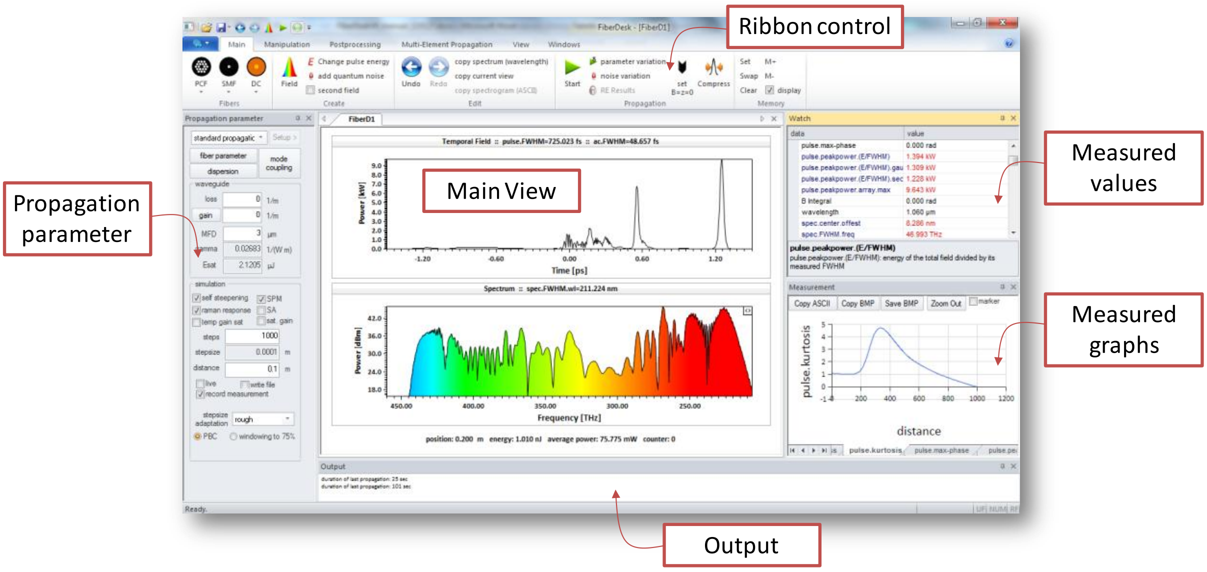


Fig. 3.1: ***fiberdesk**: graphical interface layout.*

Since version 2.0 of **fiberdesk**, the new ribbon control has been added (*Fig. 3.1*). Its structure is comparable to a menu, but with advanced features and easier access to the command structure. It is explained in section 3.1.

Beside the main view, additionally information and setups are displayed in four attachable windows. These four windows are the propagation window, the measured value window, the output window and the graph window. More details can be found in section 3.2.

3.1. MENU STRUCTURE: THE RIBBON CONTROL

The general structure of the ribbon control is shown in *Fig. 3.2*.

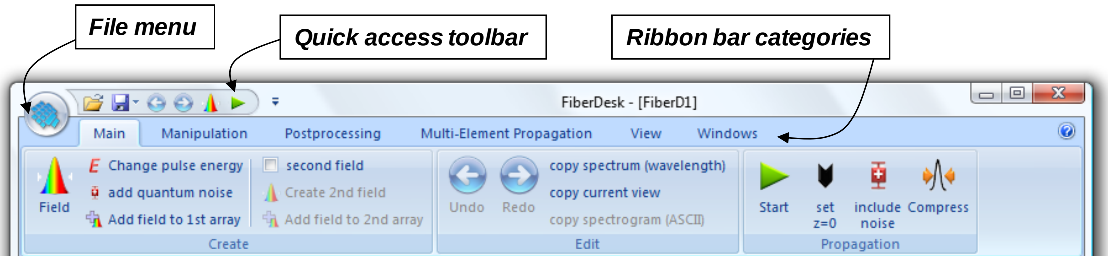


Fig. 3.2: Structure of the ribbon control.

3.1.1. FILE MENU

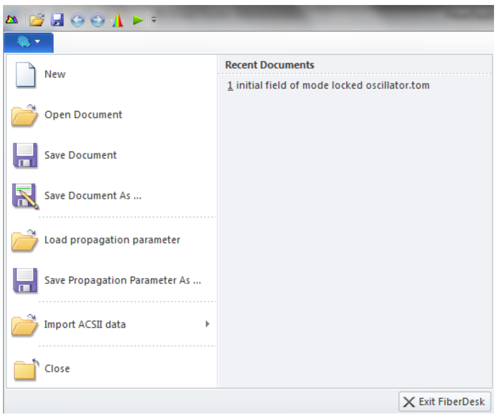


Fig. 3.3: *The file menu.*

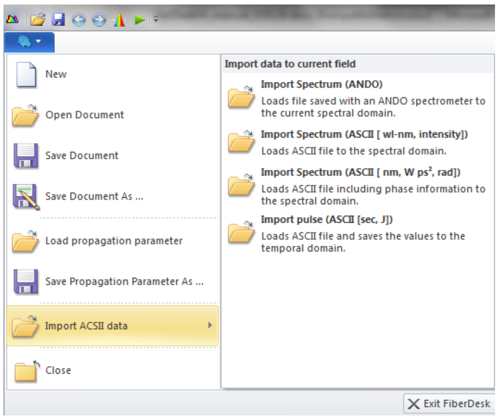


Fig. 3.4: *Import menu*

The file menu (*Fig. 3.3*) includes all command to control data connected to a file.

New

Creates a new document (field) and sets most controls to standard values.

Open Document

Opens a previously saved file.

The *file* contains the *data array* sampling the electric field as well as the element container (see File Description), no information about any propagation parameter are saved.

Save / Save As …

Saves the current field to a file including the element container.

Load propagation parameters …

Loads the propagation parameters from a specific file.

Export propagation parameters …

Saves the propagation parameters to a specific file.

Import ASCII files (see Import menu below)

Close

Closes the current document file.

Exit

Quit Fiberdesk.

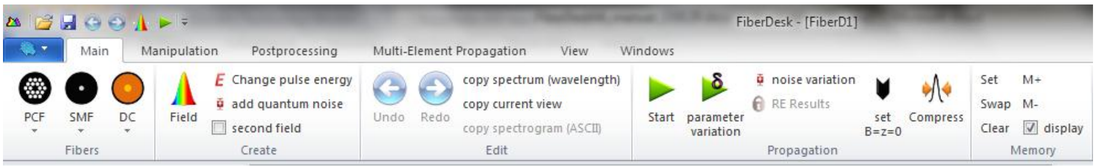
The **Import ASCII menu** (*Fig. 3.4*) menu allows importing various ASCII files:

Import spectrum (ANDO)

Imports an ANDO spectrum file and sets the phase to zero.

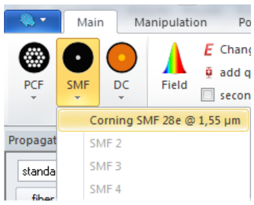
Important for ASCII/ANDO imports: The actual data array dimensions are kept constant, thus, be sure to provide enough datapoints and the right spectral range for the given file. This means, first “create a pulse” with the right bandwidth and central wavelength.

3.1.2. Ribbon control: Main



Panel: Fibers

PCF / SMF / DC



Several predefined fibers are available. PCF – photonic crystal fibers, SMF – single mode fibers, DC – double clad fibers

The following table gives information about the used parameters:

Corning SMF 28e @ 1.55 µm

From Corning’s datasheet of fiber SMF 28e, the dispersion can be calculated using:

Formulas

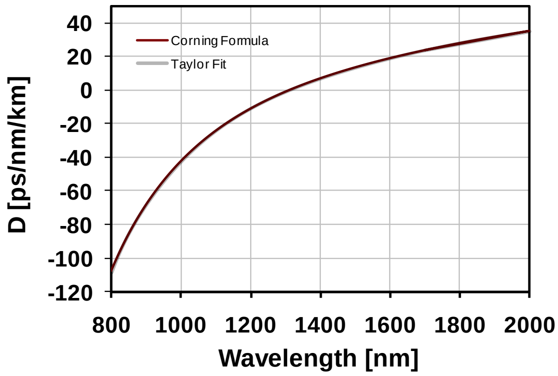
Dispersion

$$\text{Dispersion} = D(\lambda) :\approx \frac{S_0}{4}\left[\lambda - \frac{\lambda_0^4}{\lambda^3}\right] \text{ps/(nm·km)},$$

for $1200 \text{ nm} \leq \lambda \leq 1625 \text{ nm}$

λ = Operating Wavelength

with the zero dispersion wavelength of λ_0=1313 nm and S_0=0.086 ps²/nm²/km the zero dispersion slope. The Taylor fit at 1550 nm to this dispersion data is used in fiberdesk. The MFD@1550 nm is set to 10.4 µm.



more to come …

…

Panel: Create

Field

This calls the main dialog for setting up a simple pulse and the corresponding temporal and spectral parameters for the simulations.

- Size (DP): number of data points of the field

- Type: shape of the temporal pulse intensity (Gauss, sech², Parabolic, Rect) Additionally, one can select a specific spectral shape

- Half interval (HI): Half of the temporal width of the complete field. The dwell time is therefore given by t_{DW} = 2 * HI / DP. Of course, this sets the spectral width and resolution due to Fourier theorem.

- FWHM: full width at half maximum of the pulse width

- TempShift: offset of the position of the pulse center τ

- Double pulse separation τ_{dp}

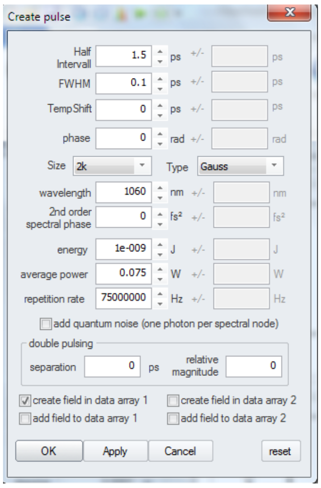
- Relative magnitude R

- Center wavelength: central wavelength of the pulse spectrum

- Chirp: linear spectral chirp

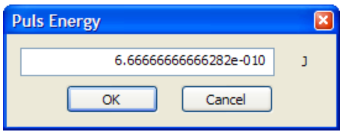
The double-pulse separation, temporal shift and relative magnitude is calculated from the complex single-pulse field amplitude A(T) by

$$A_{new}(T) = \frac{(1-R)A(T-\tau_{dp}+\tau)+(1+R)A(T+\tau_{dp}+\tau)}{2}$$



Change pulse energy

Changes the pulse energy of the current pulse.



Add quantum noise …

Adds one photon per spectral mode with random phase.

Use second field

Enables or disables the second data array for a second field that can be coupled through the NLSE by XPM or birefringence.

Please ask webmaster@fiberdesk.com for details.

Panel: Edit

Undo

Undo last change in the dataarray. The selected area is set to the full size of the dataarray.

Redo

Restore last undo step.

Copy spectrum (wavelength axis)

Copy spectrum to clipboard as ASCII. The wavelength axis is obtained by linear interpolation from the frequency axis.

Copy current view

Copy current view to clipboard as enhanced metafile (EMF).

Copy spectrogram as ASCII matrix

If spectrogram view is active, copy all values to clipboard as ASCII matrix.

Panel: Propagation

Start

Start the propagation using the current settings.

Parameter variation

Vary one or two parameters of a propagation using the dialog in Fig. 3.5.

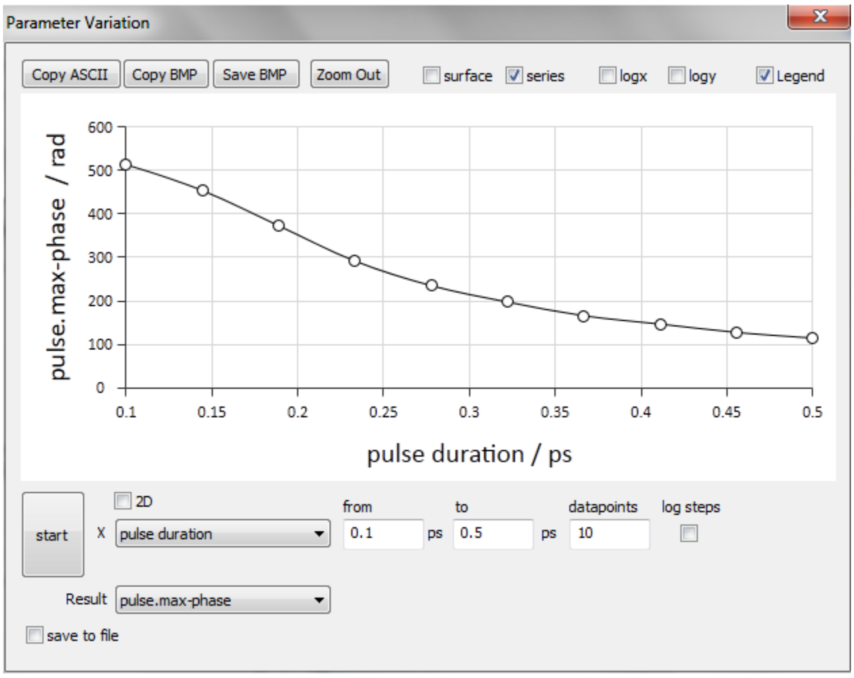


Fig. 3.5: Parameter Variation Dialog.

Depending on the parameter to vary, the field is create with the new parameter and propagated using the parameters set up so far. All measurements are done after propagation so that the results can be displayed without a new calculation.

The parameters are varied linearly or with equal logarithmic setup, if “log steps” is choosen.

A second parameter can be varied by choosing “2D”. The display of the results can either be a series plot or 2D surface plot (see Fig. 3.6).

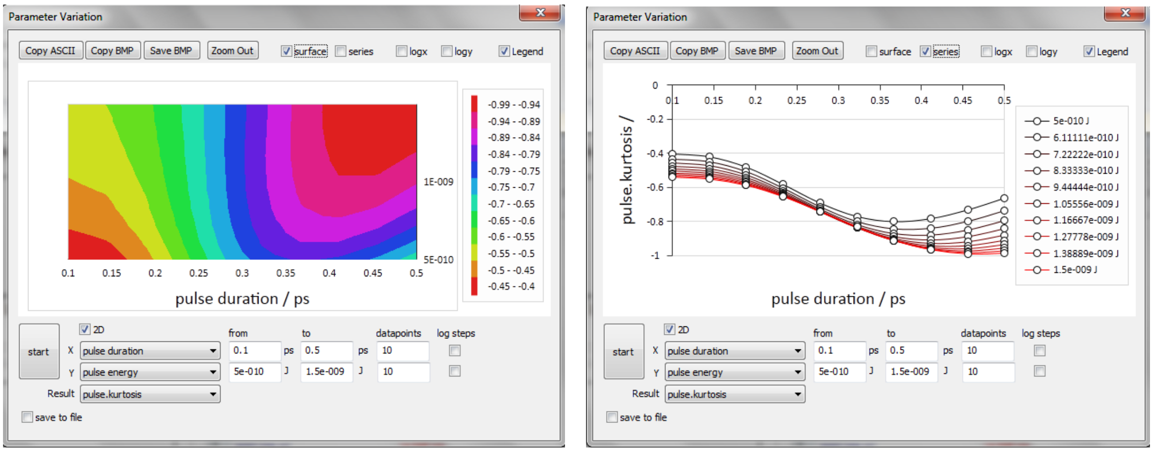
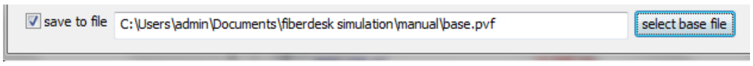


Fig. 3.6: 2D Parameter Variation displayed by a surface plot (left) or series with legend (right).

The resulting fields of the parameter variation propagation can be saved by choosing a base file:



The following files are saved in this case:

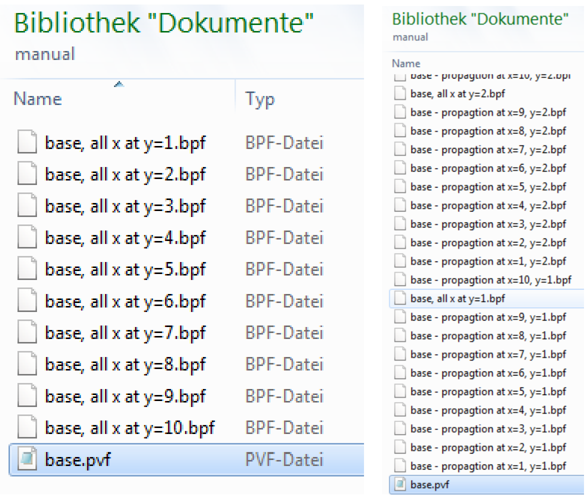


Fig. 3.7: File structure in the parameter variation dialog (left) without and (right) with individual propagation saved.

Each individual propagation can also be saved by combining the "save to file" option with the "write file" option in the general setup for the propagation parameter outside this dialog. Then the file structure looks like:

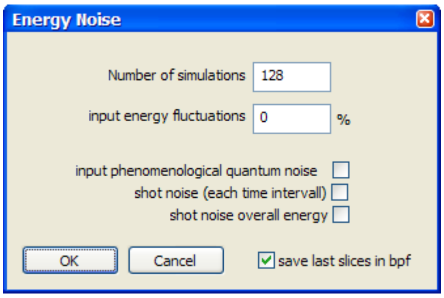
Set z=B=0

Set propagation position and B-integral value to zero.

include noise

Starts a propagation multiple times by adding specific noise sources on the initial pulse. The number of propagation is given by "Number of simulations".

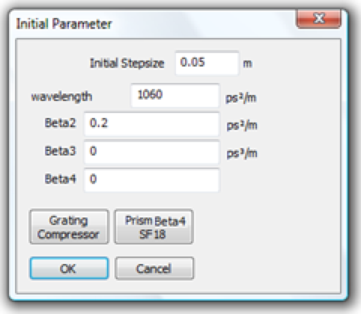
- input phenomenological quantum noise: one photon with random phase is added per frequency intervall
- shot noise (each time intervall): Poisson noise on each temporal datapoint
- shot noise overall energy: poisson noise variation of the pulse energy



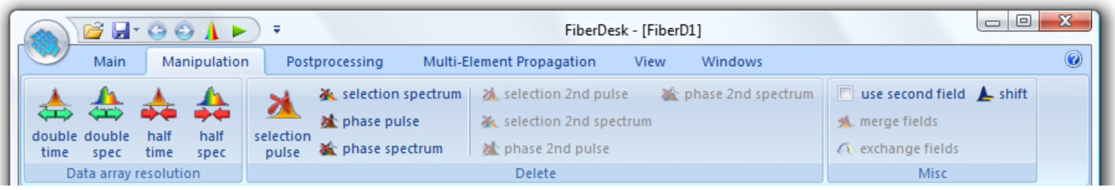
If the option “save last slice in bpf” is chosen, the result of each propagation is saved in a file for further processing and analysis, see menu “postprocessing”. In combination with the usual “write file” option, each full propagation is saved in a file array.

Compress

Minimizes the autocorrelation FWHM by a linear propagation (dispersion only) using the dispersion values given in the dialog.



3.1.3. Ribbon control: Manipulation



Panel: Data array resolution

double time

Doubles the number of points by increasing the temporal range. Resets the selection as well.

double spec

Doubles the number of points by increasing the spectral range. Resets the selection as well.

half time

Halfs the number of points by decreasing the temporal range. Resets the selection as well.

half spec

Halfs the number of points by decreasing the spectral range. Resets the selection as well.

Panel: Set value to zero

selection pulse

Set field to zero for all data points inside the selection in the temporal domain.

selection spectrum

Set field to zero for all data points inside the selection in the spectral domain.

phase spectrum

Set phase to zero in the whole spectral domain.

Panel: Misc

exchange fields

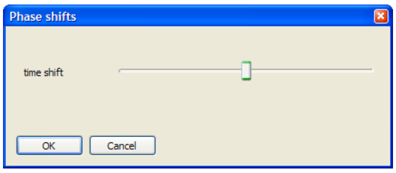
If two fields are used, its content is exchanged.

merge fields

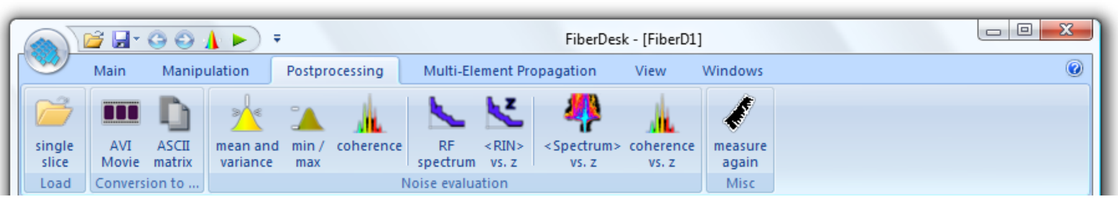
If two fields are used, its content is merged in the first field.

shift

Allows to shift the field in time.



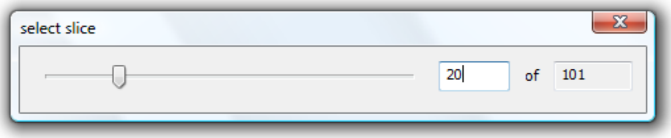
3.1.4. RIBBON CONTROL: POSTPROCESSING



Panel: Load

single slice

Reload a previously saved slice from a beam propagation file. Choose the slice number by using the following slider control or manually type the requested slice:



During this slice selection, every view control (e.g. data selection and zoom) can be used. Use this function in prior to following visual post-procession tools (e.g. movie creation) or to check the slice from a long term propagation.

Panel: Conversion to …

AVI movie

The movie is created by using the current view. The following steps have to be done:

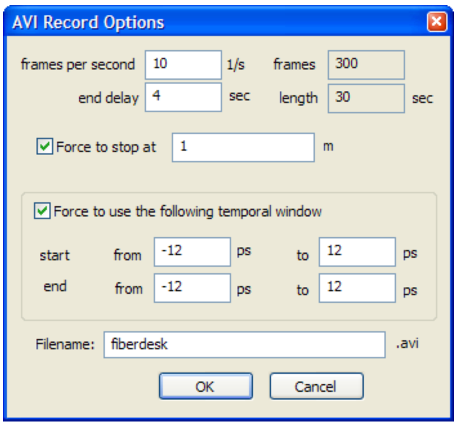
Select a previously saved propagation file.

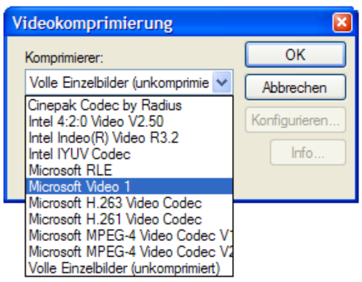
Using the AVI creation dialog, one can specify the number of frames per second and an end delay, which shows the last frame for that time.

If the propagation is longer than required for the AVI use the option “force to stop at”.

If a specific temporal window is given, the current selection is overwritten and the values of the dialog are used. This can be used to create an artificial co-moving time frame.

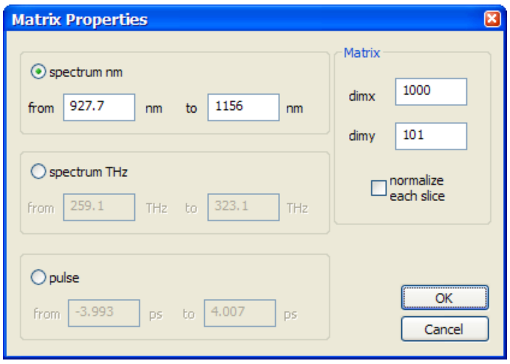
Choose a name for the AVI file, and then press OK to accept the settings. After the first screen is saved to the AVI file, select a compression scheme. The recommended scheme is “MS Video 1”.





ASCII matrix

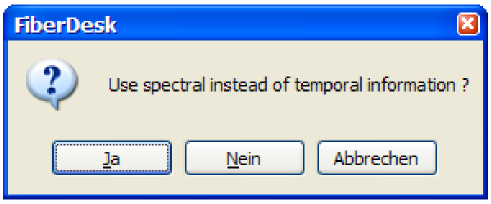
Chose a previously saved propagation file. An ASCII copy of the temporal or spectral evolution is copied to the clipboard for further processing in other softwares, e.g. ORIGIN™. In the corresponding dialog, please chose the content, which is to copy and the dimensions of the ASCII matrix. Choose “normalize each slice” to do so.



Panel: Noise evaluation

mean and variance

Especially, if the propagation file contains data from the noise variation simulation, this function helps you to calculate the mean (average value) and the variance of the data. Decide if the spectrum or temporal field should be used for the evaluation. The result is copied to the clipboard in a three-column ASCII format.



min/max

The minimum and maximum values in the spectral or temporal domain are calculated from a previously saved propagation file. The result is copied to the clipboard in an ASCII format.

coherence

Calculates the coherence (see [4]) from a single propagation file according to the following equation: $|g_{12}(\lambda)| = \left| \frac{\langle E_1^*(\lambda) E_2(\lambda) \rangle}{\sqrt{\langle |E_1(\lambda)|^2 \rangle \langle |E_2(\lambda)|^2 \rangle}} \right|$

RF spectrum

Calculates the radio frequency spectrum of a series of pulses S_i by taking the Fourier transform of the array $|S_i|^2$. The temporal spacing $t_{i+1}-t_i$ is given by the current repetition rate setting f_R, thus, the radio frequency range is $-f_R/2 \ldots f_R/2$. The result is copied to the clipboard in ASCII format.

<RIN> vs. z

Calculates the average relative intensity noise (RIN) along a previously saved propagation distance. A number of propagation files are required for this function. Each propagation file contains a single propagation. The propagations just differ in their noise properties.

<Spectrum> vs. z

Calculates the average spectrum along a previously saved propagation distance. A number of propagation files are required for this function. Each propagation file contains a single propagation. The propagations just differ in their noise properties.

coherence vs. z

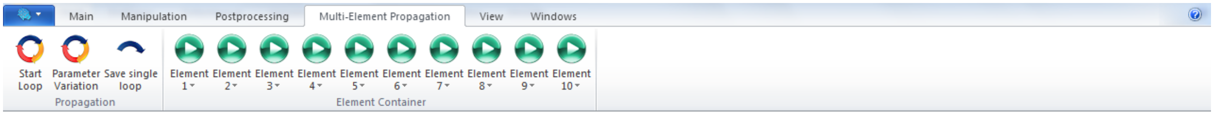
Calculates the coherence along a previously saved propagation distance. A number of propagation files are required for this function. Each propagation file contains a single propagation. The propagations just differ in their noise properties.

Panel: Misc

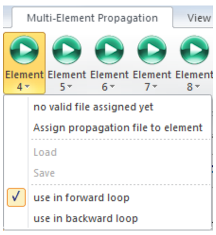
measure again

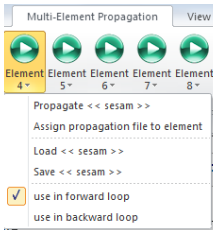
This function measures all values along a previously calculated and saved propagation file (*.bpf).

3.1.5. Ribbon control: Multi-Element Propagation



Within this category previously saved propagation files can be assigned to a button (in the Element Container) for fast (or often required) propagations. Additionally, all propagation files can be used in a loop in "forward" and "forward and backward" direction. One can also directly load and save the assigned propagation parameter file. Use this panel for simulating short pulse resonators.

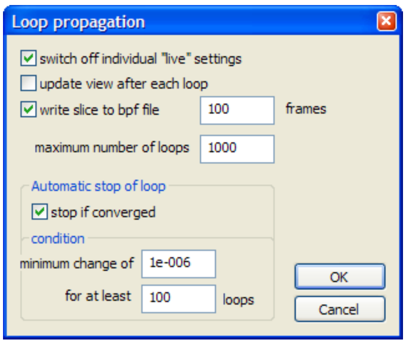


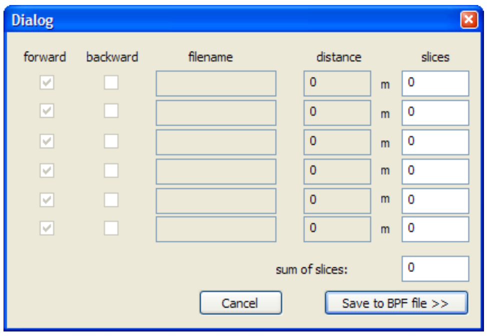


Panel: Propagation

Start Loop

Executes the loop propagation, type the number of loops and start by pressing "OK". The options "write to a propagation file" and "measure values" are switched off during a loop propagation. After each round trip the field can be saved to a *.bpf file with the option "write slice to bpf file".

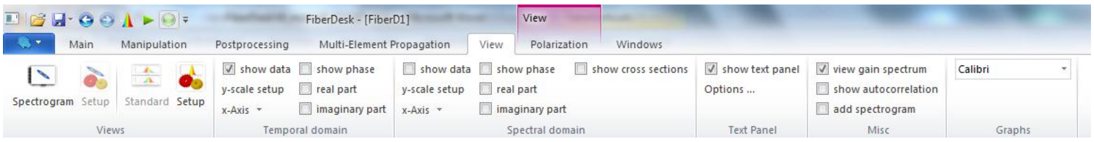




save single loop

The propagation within one roundtrip can be saved to a file by using this panel entry. The corresponding dialog resembles the loop structure and one has to specify the slices belonging to each segment.

3.1.6. Ribbon control: View



This controls the setup and appearance of the view.

Panel: Views

Spectrogram

Switches to spectrographic view.

Spectrogram setup

If the spectrographic view is available, this opens the setup dialog for the spectrographic view (see section: View Interface).

Standard

Switches to the standard view.

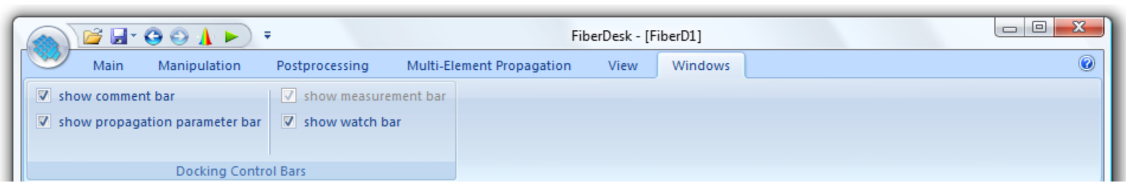
View setup

If the normal view is available, this option opens the setup dialog (see section: View Interface).

Panel: Temporal domain / Spectral domain / Misc / Text Panel

You can choose to display the intensity, phase, real and imaginary part, an additional text panel for position, energy and average power as well as switch to logarithmic scale and different Axis.

3.1.7. Ribbon control: Windows

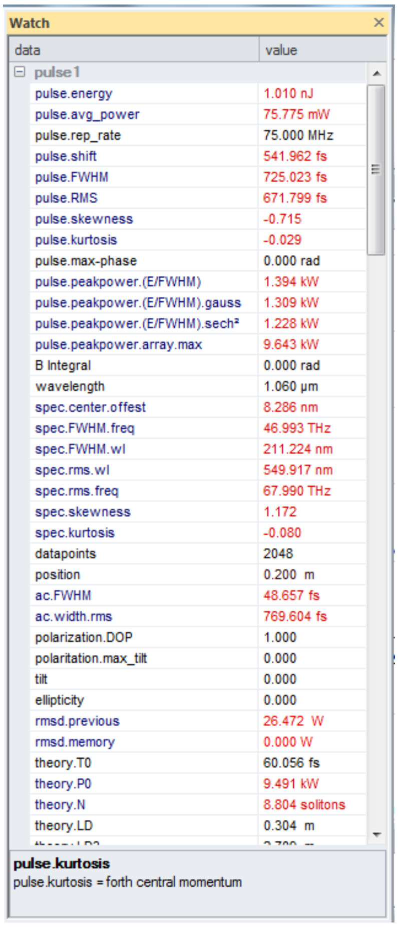


Each docking control bars can be switched on or off using the windows category.

3.2. ATTACHED WINDOWS

3.2.1. MEASUREMENT RESULTS

The current dataarray is analysed almost after each modification. The results are displayed in this separate window. SI units are used. The description is usually intuitive and displayed in the bottom of the windows when clicked on a specific measurement. To keep it short, here is a description for some of the values:



- datapoints – number of datapoints in current data array
- position – current propagation position
- FWHM – full width at half maximum
- rms – root mean square (second momentum)
- ac. – values belonging to the autocorrelation
- pulse. – values belonging to the temporal field intensity
- spec. – values belonging to the spectral field intensity
- theory. – parameters of the current propagation according to usually used normalization parameters (change is by "menu->manipulation->change T0")
- t.b. product – time-bandwidth product
- Q – quality factor in time and spectral domain (FWHM/RMS/2.0) [1]

(for more information ask webmaster @ fiberdesk.com)

3.2.2. Propagation parameter

There are six different propagation methods available: “standard fiber”, “staurable absorber”, “pulse injection”, “custom filter”, “rate equation gain”, “polarization manipulation” and “z-dependence”. The can be chosen within the propagation parameter window.

“standard fiber”

This propagation is based on solving the nonlinear Schrödinger equation. If all effects are considered, it has the following form:

$$\frac{\partial A}{\partial z} = -\frac{\alpha}{2}A + \int_{-\infty}^{\infty}\frac{g(\omega)}{2}\tilde{A}(\omega)e^{-i\omega T}d\omega + \sum_{n\geq 1}\beta_n\frac{i^{n+1}}{n!}\frac{\partial^n}{\partial T^n}A + i\gamma\cdot\left(1 + i\tau_{shock}\frac{\partial}{\partial T}\right)\left(A(T)\int_{-\infty}^{\infty}R(\tau)\left|A(T-\tau)\right|^2 d\tau\right)$$

The normalized functional form R(t) includes the vibrational contribution of the delayed Raman responds to a fraction of f_R and the instantaneous electronical contribution to a fraction of $(1-f_R)$.

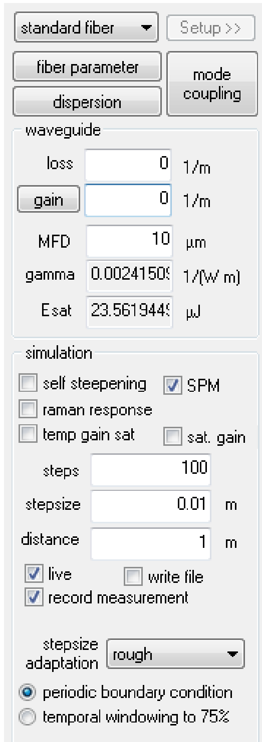
$$R(t) = (1-f_R)\delta(t) + f_R h_R(t)$$

The shock term is described by a single time scale τ_{shock}, which is defined as [6]:

$$\tau_{shock} \cong \tau_0 + \tau_A = \frac{1}{\omega_0} - \left[\frac{1}{n_{eff}}\frac{dn_{eff}(\omega)}{d\omega}\right]_{\omega_0} - \left[\frac{1}{A_{eff}}\frac{dA_{eff}(\omega)}{d\omega}\right]_{\omega_0}$$

The parameter τ_A can be changed in the “fiber parameter” dialog.

To change the parameters in this equation, the propagation parameter window is usually used. There you can directly edit the following parameters as they appear directly or indirectly:



- α / g linear loss / gain in [1/m]. Click [gain] to choose a gain profile or to select an ASCII file created by yourself in a separated dialog. The ASCII file has to have the structure: <wavelength in nm> [TAB] <positive gain in 1/m>, e.g.

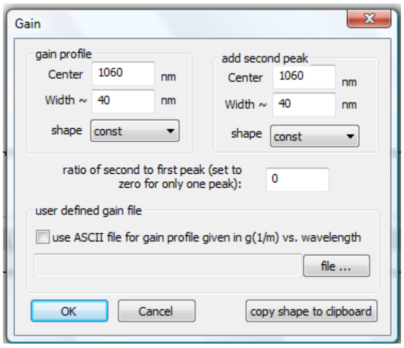
  10000

  10100.5

  10200.6

  10300.4

  10400

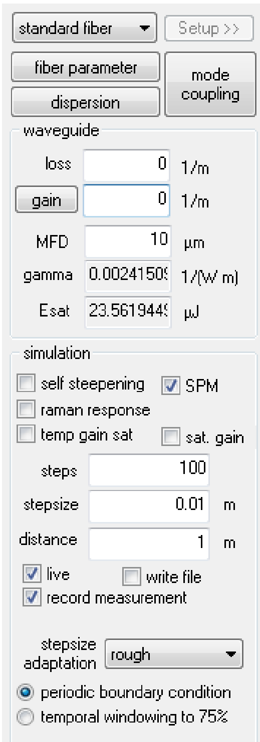


  The gain profile can also be an addition of two different profiles.

  The profiles have the following analytical forms, which are normalized and multiplied by the gain value. The parameters are converted to frequency domain for the calculation (center wavelength~ ν_c, width~$\Delta\nu$).

Lorentz	$\frac{1}{\pi}\frac{\Delta\nu}{\Delta\nu^2+(\nu-\nu_C)}$
Parabolic	Positive values of $1-2\left(\frac{\nu-\nu_C}{\Delta\nu}\right)^2$
N-th order Gauss *(supergauss2: N=2 …)*	$4\cdot\ln(2)\left(\frac{(\nu-\nu_C)^2}{\Delta\nu^2}\right)^N$
Asymmetric sech (reverse frequency axis for Asymmetric Lorentz)	$\nu<\nu_c$: $\cosh\left(\frac{\nu-\nu_c}{0.45\cdot\Delta\nu/2.041475}\right)^{-1}$ $\nu>\nu_c$: $\left(1+\frac{2\lvert\nu-\nu_c\rvert}{0.55\cdot 3.5\cdot\Delta\nu}\right)^{-2}$

- MFD – Sets the mode field diameter of the propagation mode in [µm]. It is used to calculate the nonlinear coefficient g by $\gamma=\omega/c*n_2/A_{eff}$ with $A_{eff}=\pi$*MFD. Also it determines the saturation energy E_{sat} (see also [temp gain sat] below and [2]). The parameter n_2 can be changed in the "fiber parameter" dialog.
- SPM – check this to use the SPM term in the NLSE.
- gain saturation – check this to simulate gain saturation effects in the NLSE by $g = g_0/(1+E/E_{sat.gain})$. The value of $E_{sat.gain}$ is set in the fiber parameter dialog by [gain saturation].

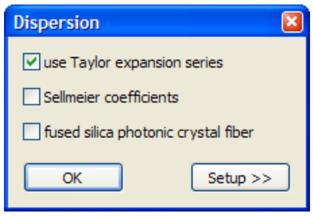


temp gain sat – check this to approximately simulate the temporal gain saturation effects meaning that the front depletes the gain and is amplified more than the pulse trail. This can be observed for long pulses with a pulse energy close to the saturation energy of the fiber E_{sat}, which is calculated automatically (for details see [2]).

- self steepening – check this to simulate the self-steepening effect.
- Raman response – check this to simulate the delayed Raman response.
- steps, stepsize, distance – Set the distance to propagate and the corresponding stepsize by these values. It determines the accuracy of the Split-Step algorithm. Even if the adaptive step size option help to avoid numerical errors, decrease the step size to ensure the numerical result.
- live – If this option is selected, the current view is updated each step set by "stepsize". It does not update the view, if the adaptive algorithm changes the stepsize. Of course, redrawing of the view slows down the computation.
- record measurement – Select this option to record the measurements (measurement window) of the data array after each step to the memory. The result is directly shown in the attached "graph window".
- write file – Select this option to write a specific number of slices of the propagation to a propagation file (*.bpf). Use this to write files that are required for most post-processing functions.

- stepsize adaption – none/rough/normal/precise/accurate – This determines the adaptive stepsize control. If the change in the electric field increases during propagation, the stepsize is reduced.
- periodic boundary condition – Use this setting to propagate with periodic boundary conditions. That is, if a part of the field travels out of the temporal window, it will enter it from the other side.
- temporal windowing to 75 % - Use this setting to randomly absorb the electric field that is entering the temporal border.

There are also several dialogs available to change additional parameters:

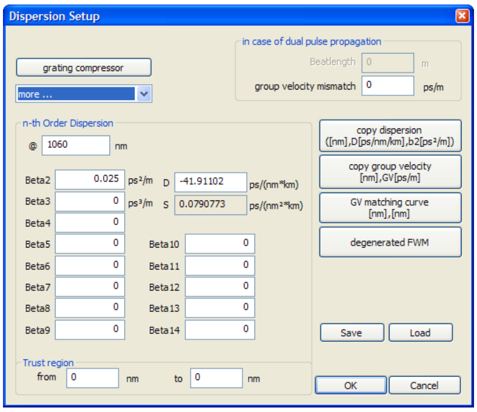


The dispersion is changed in the "Dispersion dialog" by using the following options:

- Taylor expansion series

It is specified by the coefficients β_n according to the following equation (Taylor series expansion):

$$\beta(\omega) = n_{eff}(\omega)\frac{\omega}{c} = \beta_0 + \beta_1(\omega-\omega_0) + \frac{1}{2}\beta_2(\omega-\omega_0)^2 + \frac{1}{6}\beta_3(\omega-\omega_0)^3 \dots$$



The center wavelength/frequency of this Taylor series expansion ω_0 is also required. Specify a trust region. It determines in which wavelength range the Taylor series generates values, which are physically right. Outside this region, the dispersion is set to zero. If the range is set to zero, the full range is used for evaluating the Taylor series.

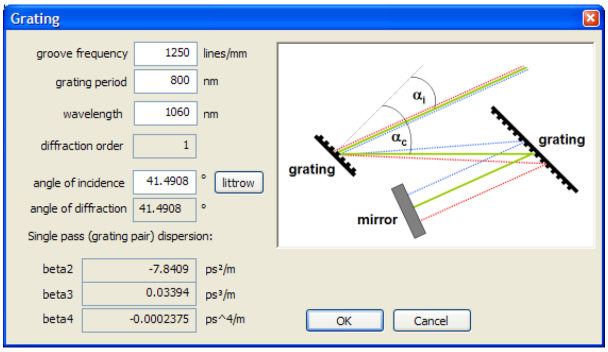
Additionally, it is possible to select several fibers from the pre-settings as well as to save or load the dispersion settings.

Automatically, the parameters of β_2 and β_3 are converted to the dispersion parameter D and its slope $S=dD/d\lambda$ according to:

$$D = -\frac{2\pi c}{\lambda^2}\beta_2$$

$$S = -\frac{2\omega^3}{(2\pi c)^2}\beta_2 + \frac{\omega^4}{(2\pi c)^2}\beta_3$$

If the center wavelength of the current spectral domain does not correspond to the Taylor series expansion wavelength of the dispersion, the Taylor series is automatically recalculated (internal). During this operation, a group delay (and fast varying amplitude due to the offset frequency) usually appears at the center wavelength of the pulse. To compensate for that, the option "always use retarded time frame" is used to set both values to zero ($\beta_0^{new}=\beta_1^{new}=0$). Thus, the retarded time frame is always at the center wavelength of the spectral domain and the most slowly varying amplitude envelope is used.



- grating compressor

In the Taylor series expansion dialog, the dispersion of a typical grating compressor in single pass can be calculated. The drawing in the dialog visualizes the parameters (m = diffraction order).

The dispersion is calculated according to:

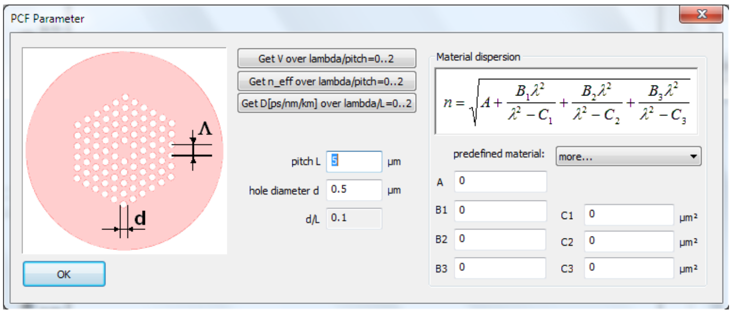
$$\sin(\alpha_c) + \sin(\alpha_i) = m\frac{\lambda}{\Lambda}$$

$$\beta_2 = -\frac{1}{c}\frac{m^2}{\omega^3}\left(\frac{2\pi c}{\Lambda}\right)^2 \frac{1}{\cos(\alpha_c)^3}$$

$$\beta_3 = -3\beta_2 f \quad \text{with} \quad f = \frac{1}{\omega} + \frac{m}{\omega^2}\frac{2\pi c}{\Lambda}\frac{\sin(\alpha_c)}{\cos(\alpha_c)^2}$$

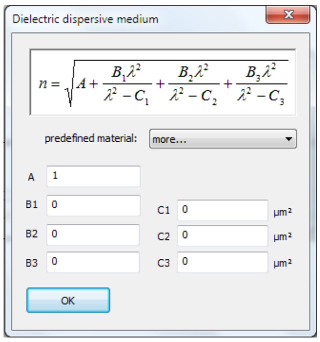
$$\beta_4 = \beta_2\left(12 f^2 + 3\frac{m^2}{\omega^4}\left(\frac{2\pi c}{\Lambda}\right)^2 \frac{1}{\cos(\alpha_c)^4}\right)$$

- fused silica photonic crystal fiber



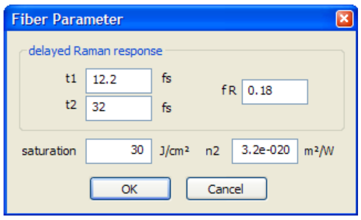
By specifying the hole to hole distance (pitch) and the hole diameter, the dispersion of a one missing hole solid core photonic crystal fiber can be used. The background material is assumed to be fused silica. Please see [3] for details.

- Sellmeier coefficients



The well-known Sellmeier coefficients can also be used to describe the dispersion of a material. Several predefined materials are available. Please take a look at http://refractiveindex.info for more material data.

Please also keep in mind that there are other definitions of the sellmeier equation, which might explain differences for coefficients.



The parameters of a fiber itself are set by the "fiber parameter" dialog. The parameter of the delayed Raman response is described by the following equation with it's parameters of τ_1, τ_2 and f_R, that can be changed.

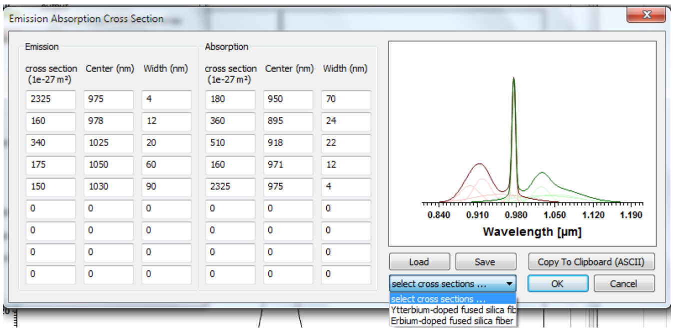
$$h_R(t) = \frac{\tau_1 + \tau_2}{\tau_1 \tau_2^2}\exp(-t/\tau_2)\sin(t/\tau_1)$$

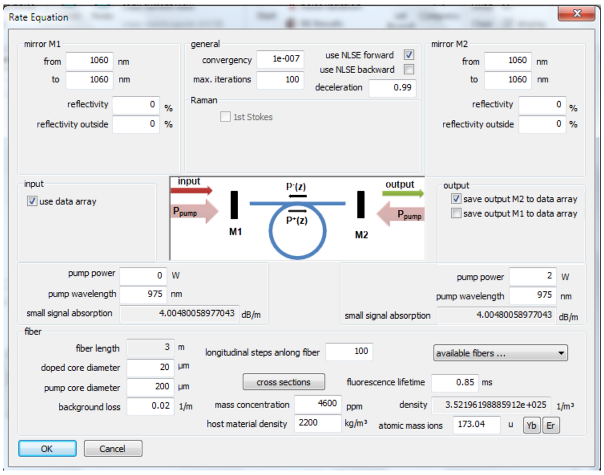
Additionally, the saturation fluence and the nonlinear refractive index can be changed.

"rate equation gain"

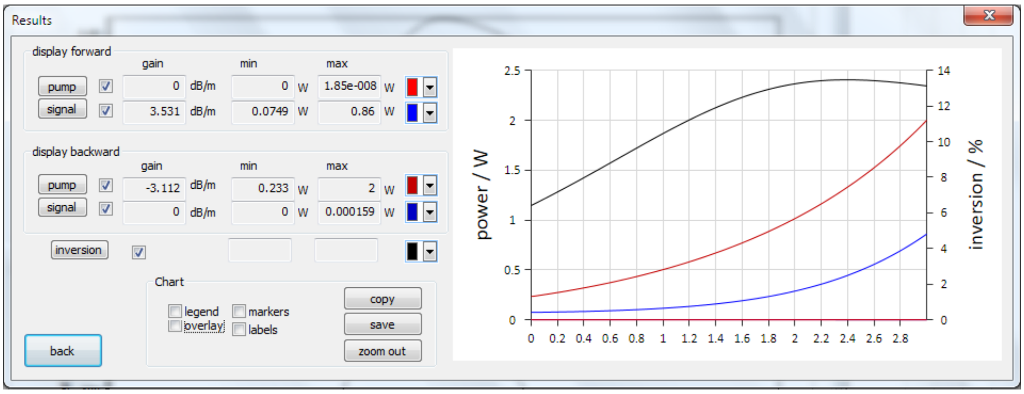
The propagation solves the NLSE similarly to "standard fiber" but includes the gain by solving the stationary rate equations. This can be used to model cw and quasi-cw amplification including ASE.

In the main dialog, all parameter are set. The cross sections can be included using a simple multi-Gaussian peak fit.





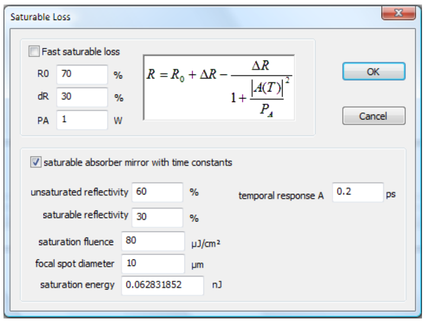
After propagation, the total powers and inversion can be accessed in the "main" section, "propagation"->"RE Results".



The options "live" and "record measurement" is disabled during the calculation. However, you can "write to a propagation file" and measure or display afterwards ("Post Processing").

"saturable absorber"

You can choose between an instantaneous saturation and a saturable element.



The first action of this element is to center the field temporally.

You can choose between an instantaneous saturation and a saturable element with a saturation that is decaying with a specific time constant.

The instantaneous saturation modifies the field intensity I(T) according to (*A* is the "field amplitude" with the unit of $J^{1/2}$):

$$I(T) = I(T) \cdot \left(R_{unsat} + \Delta R \left(1 - \left[1 + \frac{|A(T)|^2}{\tau_{dw} P_{sat}} \right]^{-1} \right) \right)$$

The unsaturable R_{unsat} and saturable reflectivity ΔR as well as the saturation power can be controlled.

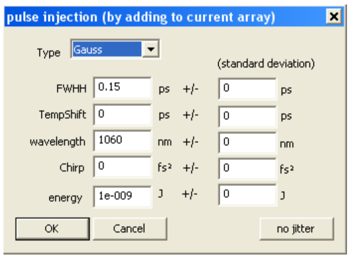
The time dependent saturable absorber modifies the field according the following rate equation with the notations q_0=ΔR and the reflectivity R=R_{unsat}+(ΔR-q(t)):

$$\frac{dq}{dt} = -\frac{q - q_0}{T_1} - \frac{|A(t)|^2}{E_{sat}} q$$

with:
q_0 – saturable reflectivity
E_{sat} – saturation energy
A(t) – field envelope in [$J^{1/2}$]
q(t) – response of SESAM

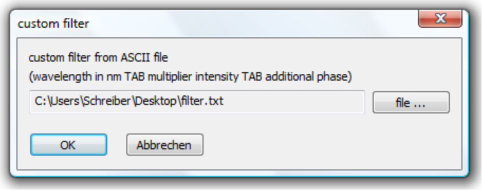
The unsaturable and saturable reflectivity can be controlled directly in the dialog. The saturation energy E_{sat} is controlled by controlling the focal spot and the saturation fluence (as known from semiconductor saturable absorber mirrors).

"pulse injection"



By this method a pulse is added to the current data array with randomly varying parameters according to the setup dialog. (Tip: In a multi-element propagation, add a high loss before this element to approximately zero the array and inject a pulse.)

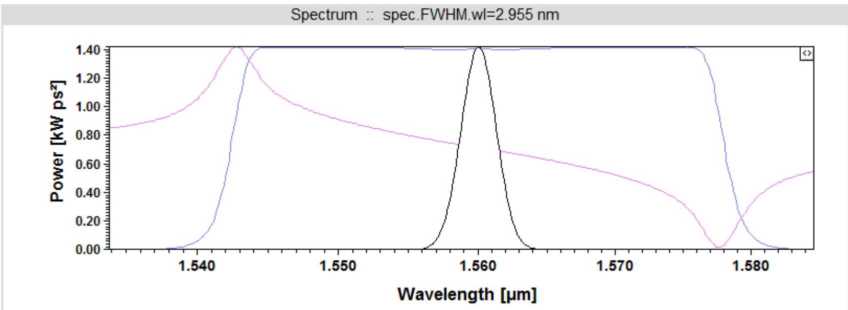
"custom filter"



This allows to select an ASCII file with a custom defined transmission T(ω) for the spectral intensity and an additional spectral phase φ(ω). It is combined with the spectral field amplitude as follows: $\tilde{A}(\omega) \rightarrow \sqrt{T(\omega)} \cdot \tilde{A}(\omega) \cdot e^{i\varphi(\omega)}$

The ASCII file has to contain three columns with the values of the wavelength in nm, the transmission T and the phase in rad. The values have to be separated by "TAB" or ",".

The imported data are displayed in the main view (normalized).

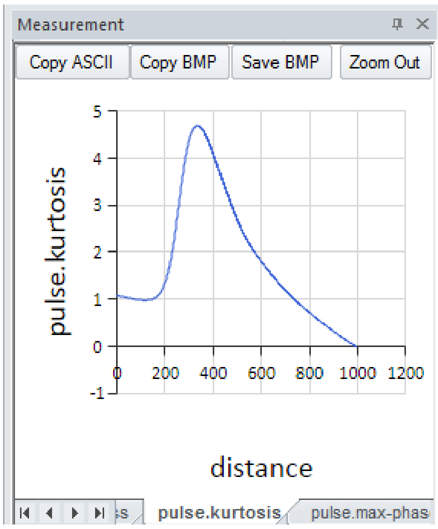


"z-dependence"

This allows to linear interpolate between parameters of a standard propagation along the propagation length. To do this, choose two propagation files for initial and final parameter values.

3.2.3. MEASUREMENT GRAPHS

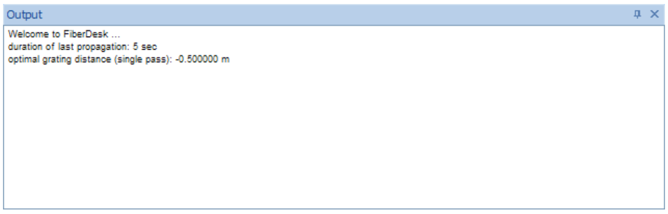
If the measurement is switch on during propagation, all measured value from the measurement result window are show with respect to the propagation distance in the "Graph" window. By using the tab-control a selection between the different values can be made.



Use the buttons on top to copy the content of the current graph to the clipboard in ASCII or BMP format or save it to a file. Zoom in to the values by moving to mouse onto the data and click left. Zoom out by the button on top.

3.2.4. OUTPUT

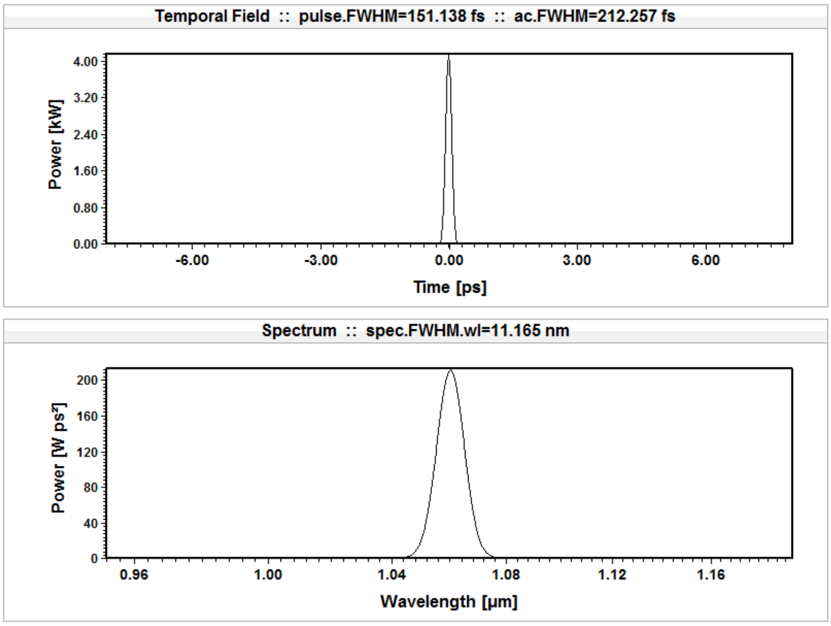
Several important information or results of the propagation are displayed in the output window.



3.3. VIEW INTERFACE

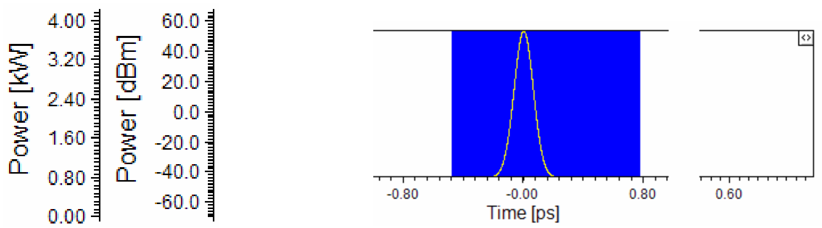
3.3.1. GENERAL VIEW

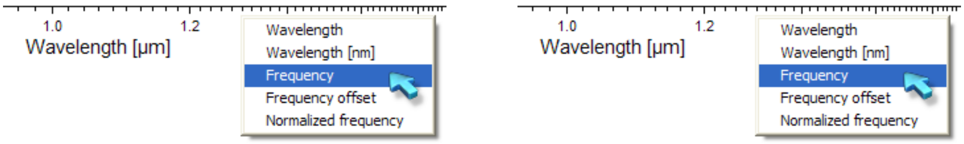
The general view can contain different views of the current electric field: the temporal field, its Fourier transformation as the spectral field and the autocorrelation. Each view can be independently switched on and off (see ribbon control “View”).



Control of the temporal and spectral view:

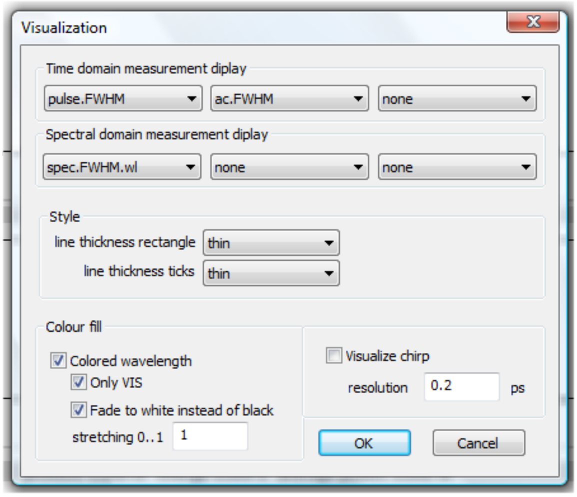
- double click the intensity axis to change from linear to logarithmic scale and to normalize the x-axis if required
- right-click the time domain x-axis to choose a different axis
- to select and zoom into the data-array, left-click on the first boundary, move the mouse to the second boundary while keeping the left mouse key clicked and release the mouse button when the selection is done, left-click into the highlighted area
- to zoom out, press the left symbol in the upper-right corner of the specific view
- double click into the view to copy the current shown area to the clipboard in ASCII format
- right-click the spectral domain x-axis to choose a different axis





An additional setup can be accessed by the ribbon control: View / Views / Setup.

There it is possible to select up to three different measured values displayed in the view for a quick access.



If the option "colored wavelength" is chosen, each wavelength is colored individually. The colors are controlled by the options "only VIS" to highlight the visible wavelength (otherwise the whole current spectral range is used) and the option "Fade to white …" to choose the colors of the wavelength that are out of the visible region.

Additionally, a fast algorithm is implemented to visualize the temporal position of the spectral components (chirp).

3.3.2. Spectrographic view

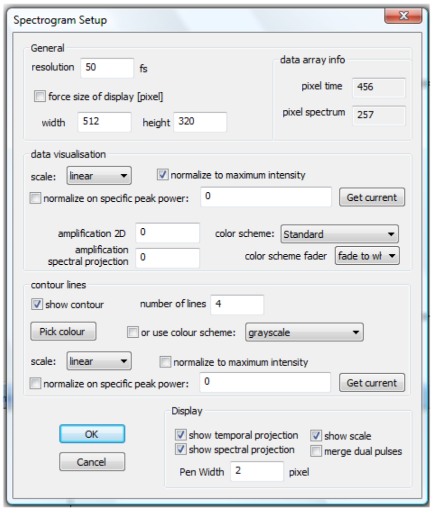
The spectrographic view shows a spectrally (wavelength) resolved temporal map of the electric field. This view is well known from the measurement technique of ultrashort pulse known as frequency resolved optical gating (FROG) [5]. It is calculated by the following equation:

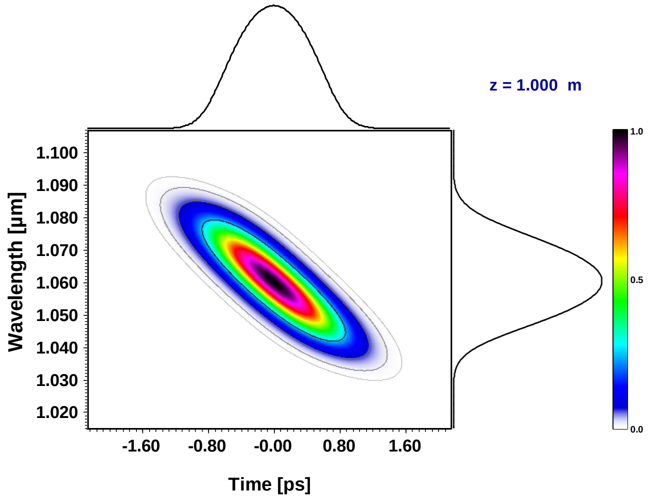
$$S(t,\lambda)=\left|\int_{-\infty}^{\infty} e^{-i\,{}^{c}\!/_{\lambda}\,\tau}\, e^{-i(\tau-t)^2/T_{BW}^2}\, A(z,\tau)\,d\tau\right|^2$$

If the axis of the spectrum in the normal view is set to any of the frequency axis, the spectrogram is also calculated in time-frequency domain.

$$S(t,\omega) = \left| \int_{-\infty}^{\infty} e^{-i\omega\tau} e^{-i(\tau-t)^2/T_{BW}^2} A(z,\tau) d\tau \right|^2$$

Right click the view (or View-> Spectrogram-Setup) to open the setup dialog of the spectrographic view:





In the graphics control panel, the temporal resolution T_{BW}, pen width of the projections, and the display size (usually used for specific movie sizes) can be chosen.

In the level control panel, the way of normalizing, changing to logarithmic scale and the amplification of the 2D intensity display and the spectrum can be chosen. Furthermore, a setup for contour plot can be done.

Additionally, the scale and projections can be switched on or off and dual pulses can be merged to a single pulse.

Furthermore, an additional contour plot overlay can be defined.

3.4. REFERENCES

[1] K. Tamura and M. Nakazawa, "Pulse compression by nonlinear pulse evolution with reduced optical wave breaking in erbium-doped fiber amplifers," Opt. Lett. 21, 1, 68 (1996).

[2] Govind P. Agrawal, "Optical pulse propagation in doped fiber amplifiers ", Phys. Rev. A 44, 7493 - 7501 (1991))

[3] K. Saitoh and M. Koshiba, "Empirical relations for simple design of photonic crystal fibers," Opt. Express 13, 267-274 (2005).

[4] J. Dudley and S. Coen, "Coherence properties of supercontinuum spectra generated in photonic crystal and tapered optical fibers," Opt. Lett. 27, 1180-1182 (2002).

[5] Rick Trebino, Kenneth W. DeLong, David N. Fittinghoff, John N. Sweetser, Marco A. Krumbügel, Bruce A. Richman, Daniel J. Kane, "Measuring ultrashort laser pulses in the time-frequency domain using frequency-resolved optical gating," Rev. Sci. Instrum. 68, 3277 (1997)

[6] B. Kibler, J. M. Dudley, and S. Coen, "Supercontinuum generation and nonlinear pulse propagation in photonic crystal fiber: influence of the frequency-dependent effective mode area," Appl. Phys. B 81, 337–342 (2005).