

Manual

FiberDesk V3.0

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2. GENERAL

2.1. SYSTEM REQUIREMENTS

2.1.1. SOFTWARE REQUIREMENTS

FiberDesk V3.0 works stable on the following operating systems:

Microsoft® Windows® 2000

Microsoft® Windows® XP Home Edition / Professional

Microsoft® Windows® Vista

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: Pentium or compatible

Recommended processor: Pentium 1 GHz or faster

Required/Recommended RAM: 128 MB / 256 MB or higher

2.2. SOFTWARE LICENSE

This program is **NOT** freeware, please see section 2.3. This means that you are not allowed to distribute it anywhere or to modify the executable or any data files within this program. Furthermore, you are not allowed to place this program on a Web Site, but you could place a link to the official website of this program. This program is provided as is. There are no guarantees for you about the safety of your data. Any suggestions and bug reports are welcome. To ask questions, get answers or report bugs visit the official web site.

Official web-site: www.fiberdesk.com



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6. UPDATES

In order to ensure that the software functions properly, the Licencor / FiberDesk publishes updates (by sending it to you by email or putting it on the official webpage). If the Software is an update to a previous version, you must possess a valid license to such previous version in order to use such update. Updates improve the workings of the software, i.e. remove bugs. The user is responsible for proper configuration of the software updating process to provide for the highest possible level of functional reliability. Updates may be licensed to you by FiberDesk with additional or different terms. Updates are distinguished from Upgrades. Upgrades to a new version including new features that were not available in Your version have to be purchased again (please contact the FiberDesk for Upgrades).

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Technical support is given for any software bug or technical question concerning the functionality of the software. Scientific support, which means that scientific question or problems are solved by the Fiberdesk support, are not included in the licence. The Licensor may ask such



questions, however, the decision for answering is done by Fiberdesk. Likewise, no consulting about scientific topics is included in the license.

9. REFERENCING FIBERDESK

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.

10. GENERAL TERMS

If any part of this agreement is found to be invalid, illegal or unenforceable, it will not affect the validity of the balance of this agreement, which will remain valid and enforceable according to its terms. This Agreement sets out the entire understanding between You and the Licensor and may only be amended in writing in a document signed by both parties.

$$\frac{dA}{dz} = \frac{\alpha}{2} A + \sum_{\nu} \beta_{\nu} \frac{d^{\nu} A}{dz^{\nu}} + A |A|^2 \left(1 - f_1 \left(1 + \frac{i}{\omega_0} \frac{\partial}{\partial t} \right) A(z, T) \int R(t') A(z, T - t')^2 dt' \right)$$



3. SOFTWARE INTERFACE

The general graphical layout of FiberDesk is shown in Fig. 3.1.

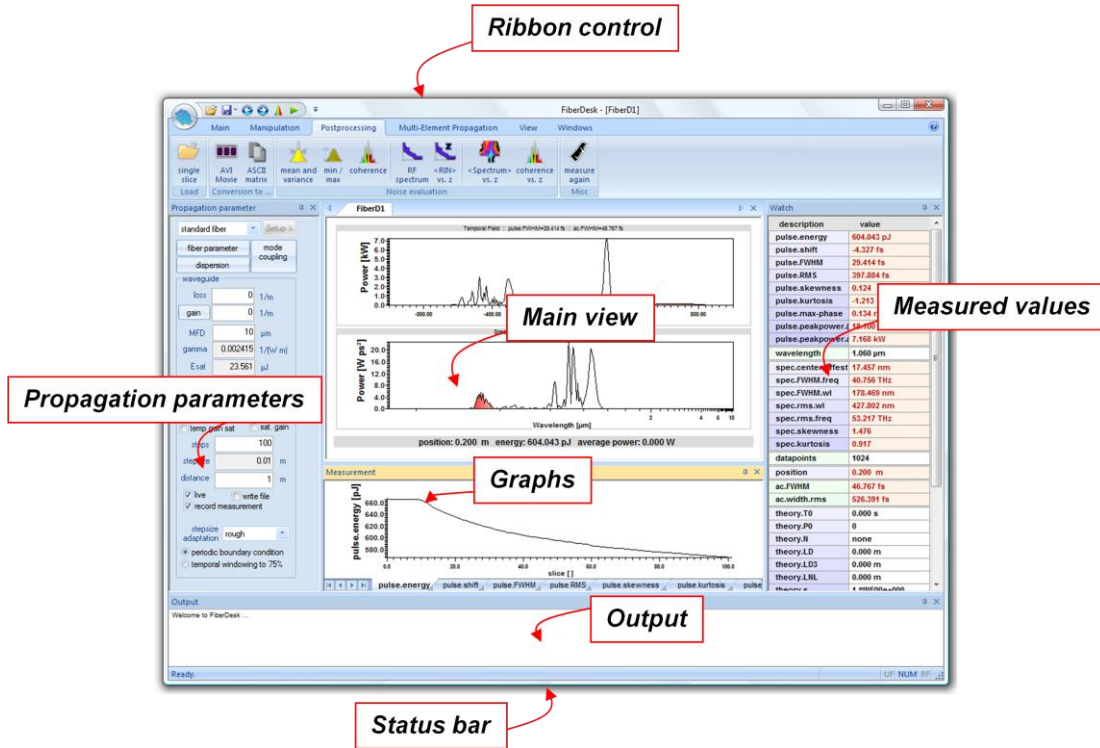
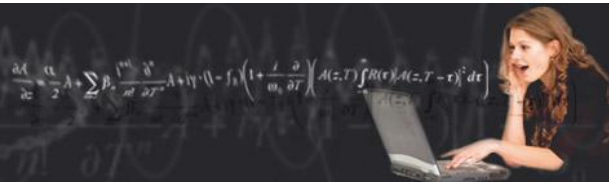


Fig. 3.1: FiberDesk graphical interface layout.

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.

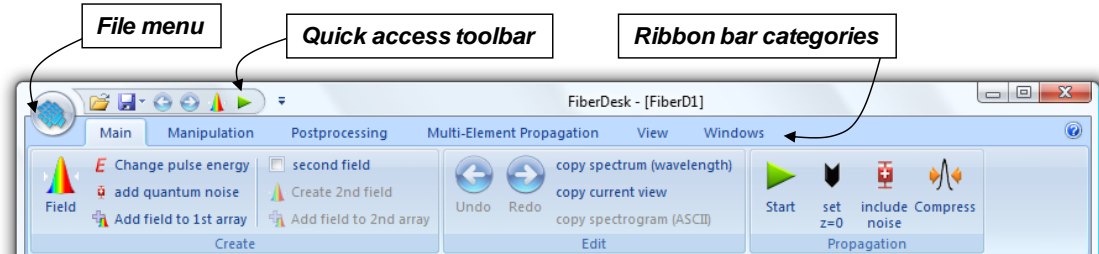


Fig. 3.2: Structure of the ribbon control.

3.1.1. FILE MENU

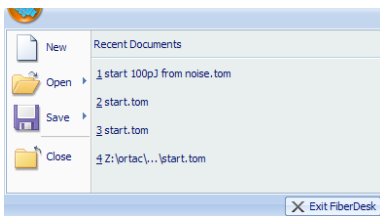


Fig. 3.3. The file menu.

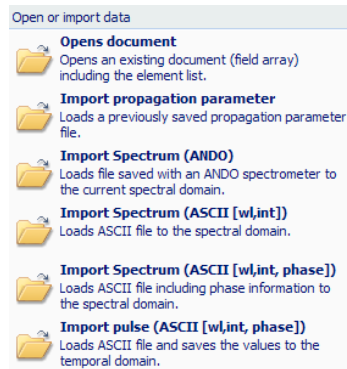


Fig. 3.4. Open menu.

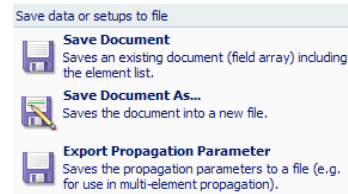


Fig. 3.5. Save menu.

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

New

Creates a new document and sets controls to standard values.

Open > (see Open Menu below)

Save > (see Save Menu below)

Close

Closes the current document file.

Exit

Quit Fiberdesk.

The Open menu (Fig. 3.4) includes all command to save and export data to a file.



Open document

Opens a previously saved dataarray file.

The *dataarray file* contains data about the electric field and the element container only (see File Description), no information about any propagation parameter are saved.

Import propagation parameters ...

Loads the propagation parameters from a specific file.

Import spectrum (ANDO)

Imports an ANDO spectrum file and sets the phase to zero. The actual dataarray dimensions are kept constant, thus, be sure to provide enough datapoints and the right spectral range for the given file.

Import ASCII

Several types of ASCII file can be imported.

The **Save** menu (Fig. 3.5) includes all command to save and export data to a file.

Save

Saves the current document dataarray file including the element container.

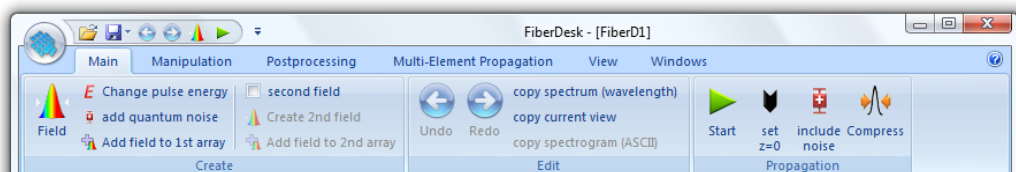
Save as ...

Saves the current document under a specific name.

Export propagation parameters ...

Saves the parameter to a specific files.

3.1.2. RIBBON CONTROL: MAIN



Panel: Create

Field

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

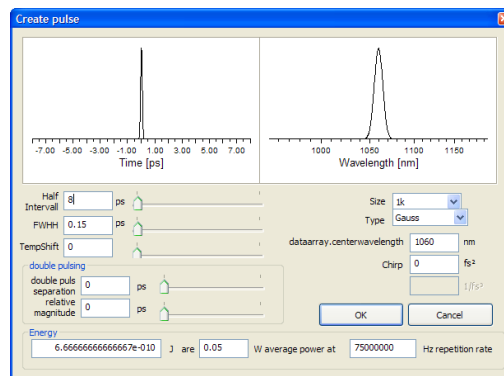
- Size (DP): number of data points of the field



- 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

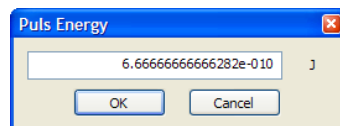
The double-pulse separation, temporal shift and relative magnitude is calculated from the complex single-pulse field amplitude $A(T)$ by

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



Change pulse energy

Changes the pulse energy of the current pulse.



Add pulse to first dataarray ...

The selected pulse is added to the current first data array (see Create Field dialog).

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

Propagate

Start the propagation using the current settings.

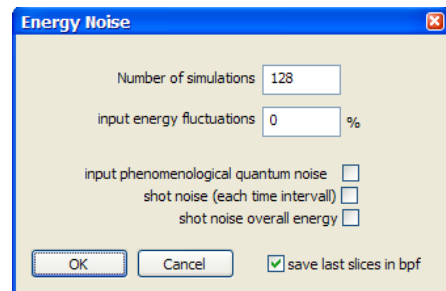
Set z=0

Set propagation position 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



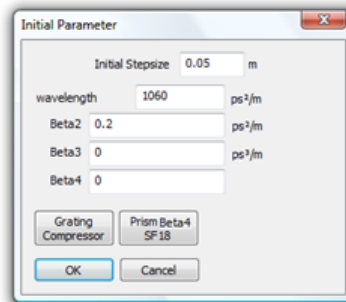


of the pulse energy

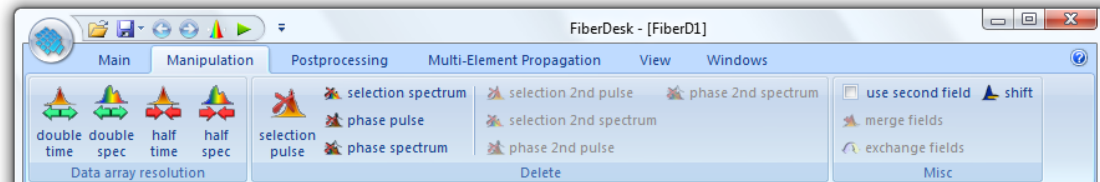
If the option “save last slice in bpf” is chosen, the result of each propagation is saved in a file for further processing and analysis, see menu “postprocessing”. In combination with the usual “write file” option, each full propagation is saved in a file array.

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

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

half spec



Halves 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

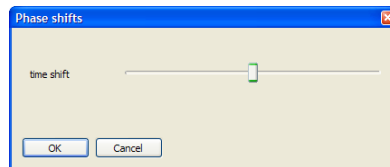
If two fields are used, its content is exchanged.

merge fields

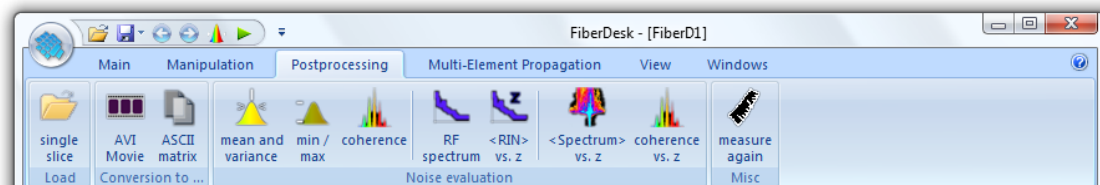
If two fields are used, its content is merged in the first field.

shift

Allows to shift the field in time.



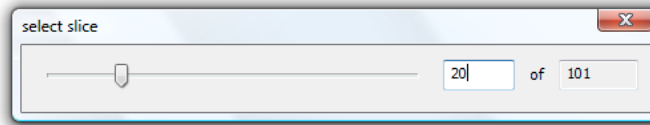
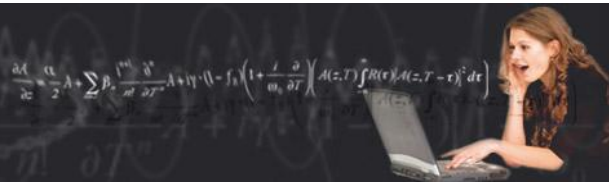
3.1.4. RIBBON CONTROL: POSTPROCESSING



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-processing 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:

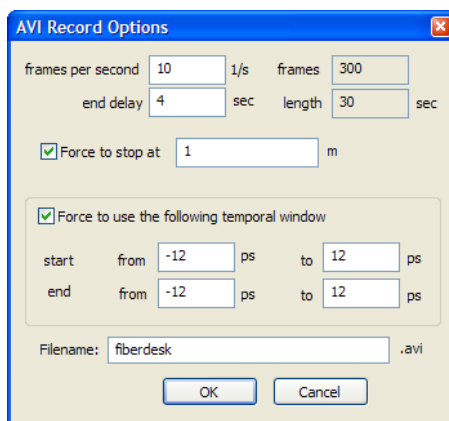
Select a previously saved propagation file.

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”.

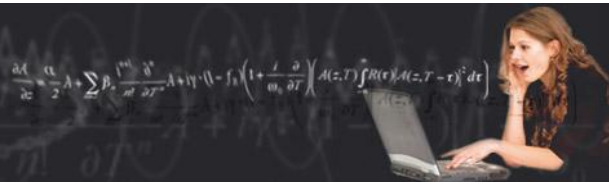
If a specific temporal window is given, the current selection is overwritten and the values of the dialog are used. This can be used to create an artificial co-moving time frame.

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”.

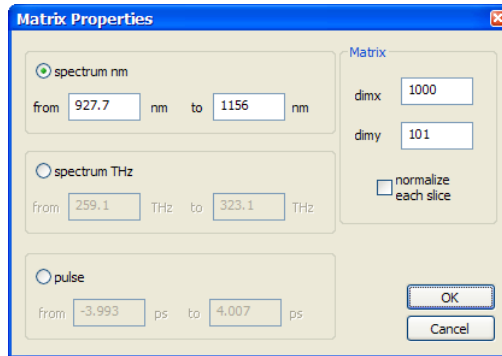


ASCII matrix

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,



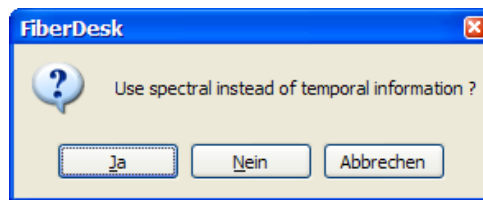
which is to copy and the dimensions of the ASCII matrix. Choose “normalize each slice” to do so.



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:
$$|g_{12}(\lambda)| = \frac{\left| \langle E_1^*(\lambda) E_2(\lambda) \rangle \right|}{\sqrt{\langle |E_1(\lambda)|^2 \rangle \langle |E_2(\lambda)|^2 \rangle}}$$

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 $-f_R/2 \dots f_R/2$. 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.

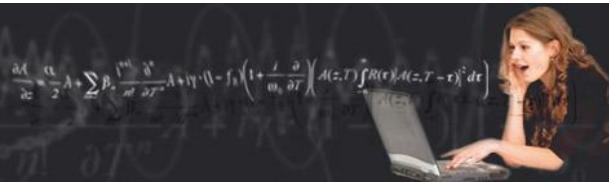
coherence vs. z

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.

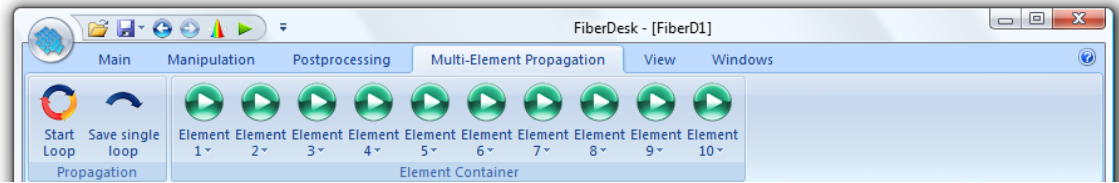
Panel: Misc

measure again

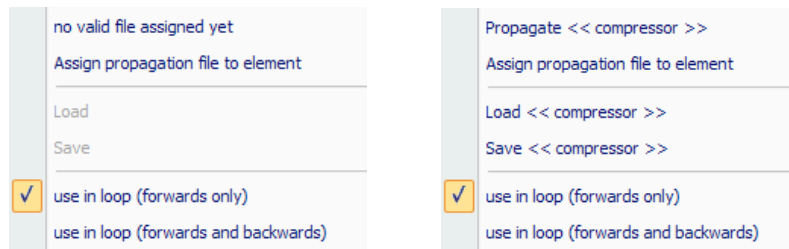
This function measures all values along a previously calculated and saved propagation file (*.bpf).



3.1.5. RIBBON CONTROL: MULTI-ELEMENT PROPAGATION



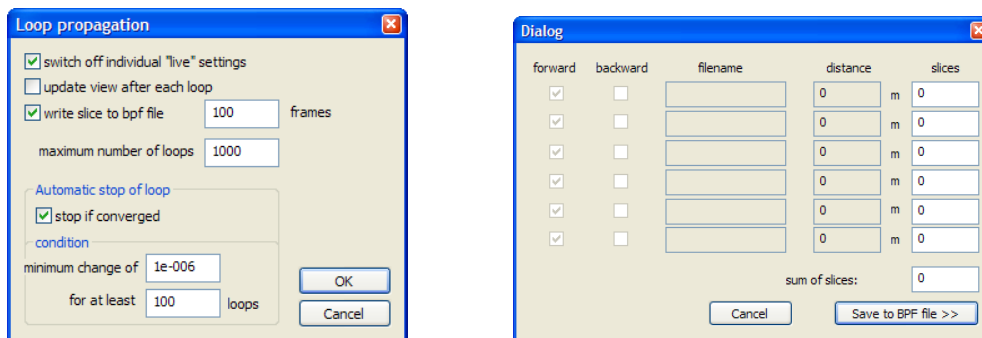
Within this category previously saved propagation files can be assigned to a button (in the Element Container) for fast (or often required) propagations. Additionally, all propagation files can be used in a loop in “forward” and “forward and backward” direction. One can also directly load and save the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

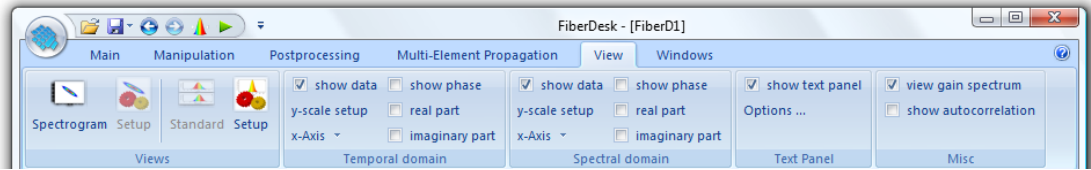


save single loop

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.

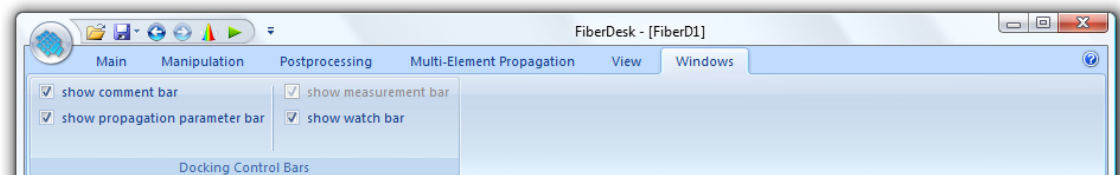
View setup

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

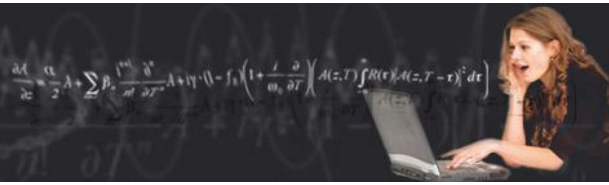
Panel: Temporal domain / Spectral domain / Misc / Text Panel

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 a separate window. SI units are used. The description is usually intuitive. To keep it short, here is a short description:

- 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)

description	value
puls.energy	98.757 aJ
puls.FWHM	12.095 ps
puls.RMS	3.635 ps
puls.skewness	-0.196
puls.kurtosis	-1.178
puls.max-phase	29.630 rad
puls.peakpower.(E/FWHM)	6.798 μW
puls.peakpower.array.max	46.506 μW
wavelength	1.030 μm
spec.center.offest	-1.825 nm
spec.FWHM.THz	115.055 THz
spec.FWHM.nm	673.312 nm
spec.rms	83.646 nm
spec.rms.freq	11.841 THz
spec.skewness	-0.049
spec.kurtosis	-1.196
datapoints	512
position	0.000 m
ac.FWHM	12.336 ps
ac.width.rms	3.595 ps
theory.T0	90.084 fs
theory.P0	618.508 μW
theory.N	0.001 solitons
theory.LD	0.325 m
theory.LD3	29.242 mm
theory.LNL	650.507 km
theory.s	6.070001e-003
special.spec	0.000 W ps ²
special.time	0.000 W/ps
rms	0.000 J
adaptive.steps per stepsize	0.000 steps
spec.max-phase	87.004 rad
t.b.product	1.392 x 10 ³
Q.time	1.664
Q.spec	4.858
N'RMS	0.000
N'FWHM	0.000

3.2.2. PROPAGATION PARAMETER

There are four different propagation methods available: “standard fiber”, “staurable absorber”, “pulse injection” and “custom filter”. The can be chosen within the propagation parameter window.

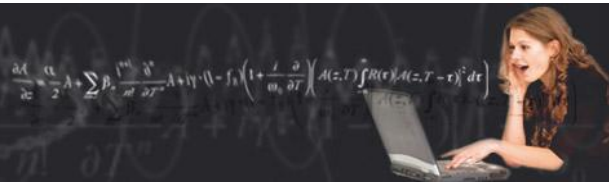
“standard fiber”

This propagation is based on solving the nonlinear Schrödinger equation. It has the following form:

$$\frac{\partial A}{\partial z} = -\frac{\alpha}{2}A + \int_{-\infty}^{\infty} \frac{g(\omega)}{2} \tilde{A}(\omega) e^{-i\omega T} d\omega + \sum_{n \geq 2} \beta_n \frac{i^{n+1}}{n!} \frac{\partial^n}{\partial T^n} A + i\gamma \cdot \left(1 + \frac{i}{\omega_0} \frac{\partial}{\partial T} \right) \left(A(T) \int_{-\infty}^{\infty} R(\tau) |A(T-\tau)|^2 d\tau \right)$$

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

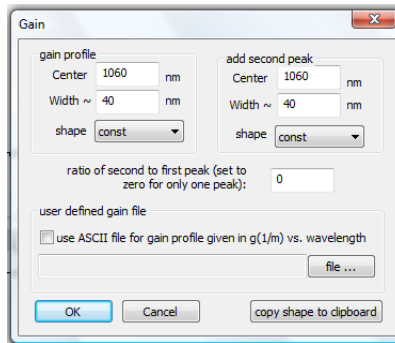
$$R(t) = (1-f_R)\delta(t) + f_R h_R(t)$$



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.

```
1000      0
1010      0.5
1020      0.6
1030      0.4
1040      0
```

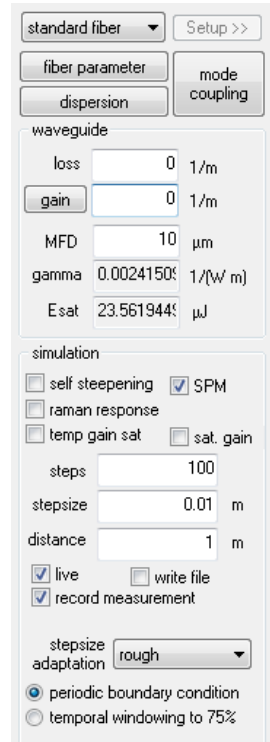


The gain profile can also be an addition of two different profiles.

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 $\sim \nu_c$, width $\sim \Delta\nu$).

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

- **MFD** - Sets the mode field diameter of the propagation mode in [μm]. It is used to calculate the nonlinear coefficient g by $\gamma = \omega/c \cdot n_2 / A_{\text{eff}}$ with $A_{\text{eff}} = \pi \cdot \text{MFD}^2$. 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 $g = g_0 / (1 + E / E_{\text{sat.gain}})$. The value of $E_{\text{sat.gain}}$ is set in the fiber parameter dialog by [gain saturation].



$$\frac{\partial A}{\partial z} = \frac{\alpha}{2} A + \sum_{\nu} \beta_{\nu} \frac{\partial^{\nu} A}{\partial t^{\nu}} + i \left(1 - f_1 \left(1 + \frac{\partial}{\omega_0 \partial t} \right) A(z, T) \int R(t) |A(z, T - \tau)|^2 d\tau \right)$$



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 dataarray 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.

standard fiber ▾
Setup >>

fiber parameter

mode coupling

dispersion

temp gain sat

waveguide

loss	<input type="text" value="0"/>	1/m
gain	<input type="text" value="0"/>	1/m
MFD	<input type="text" value="10"/>	μm
gamma	<input type="text" value="0.00241508"/>	1/(W m)
E _{sat}	<input type="text" value="23.5619448"/>	μJ

simulation

<input type="checkbox"/> self steepening	<input checked="" type="checkbox"/> SPM
<input type="checkbox"/> raman response	
<input type="checkbox"/> temp gain sat	<input type="checkbox"/> sat. gain
steps	<input type="text" value="100"/>
stepsize	<input type="text" value="0.01"/> m
distance	<input type="text" value="1"/> m
<input checked="" type="checkbox"/> live	<input type="checkbox"/> write file
<input checked="" type="checkbox"/> record measurement	
stepsize adaptation	<input type="text" value="rough"/> ▾
<input checked="" type="radio"/> periodic boundary condition	
<input type="radio"/> temporal windowing to 75%	



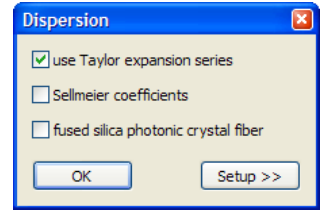
There are also several dialogs available to change additional parameters:

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

- Taylor expansion series

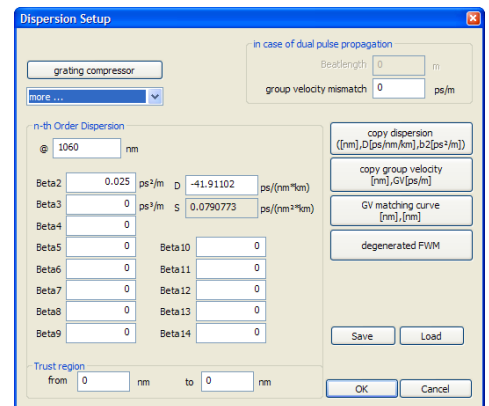
It is specified by the coefficients β_n according to the following equation (Taylor series expansion):

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



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 ($\beta_0^{\text{new}} = \beta_1^{\text{new}} = 0$). 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).

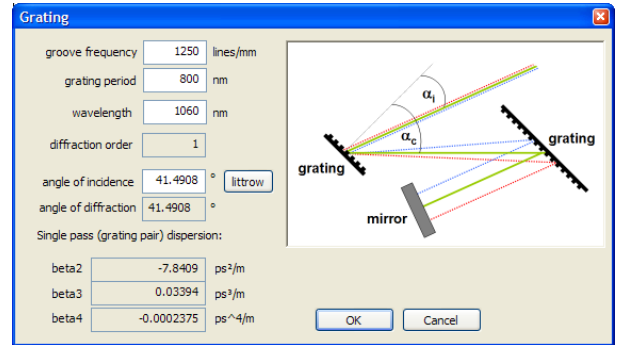
The dispersion is calculated according to:

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

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

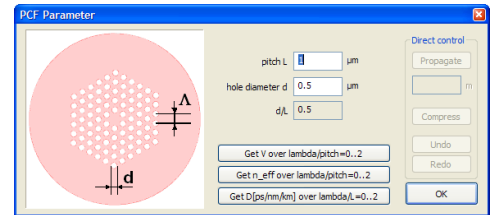
$$\beta_3 = -3\beta_2 f \quad \text{with} \quad f = \frac{1}{\omega} + \frac{m}{\omega^2} \frac{2\pi c}{\Lambda} \frac{\sin(\alpha_c)}{\cos(\alpha_c)^2}$$

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



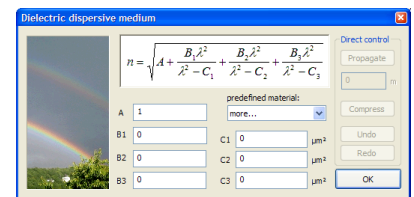
•fused silica photonic crystal fiber

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

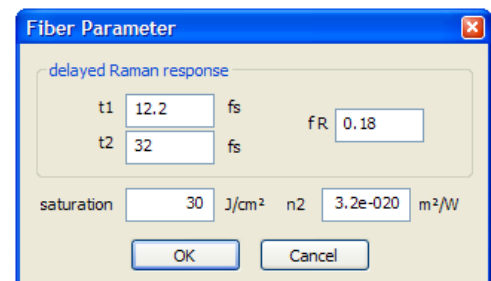
The well-known Sellmeier coefficients can also be used to describe the dispersion of a material. Several predefined materials are available.



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.

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

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

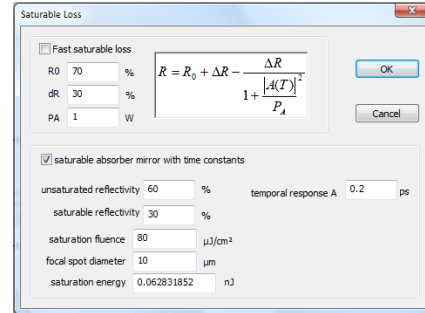




“saturable absorber”

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 $q_0 = \Delta R$ and the reflectivity $R = R_{unsat} + (\Delta R - q(t))$:

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

with:

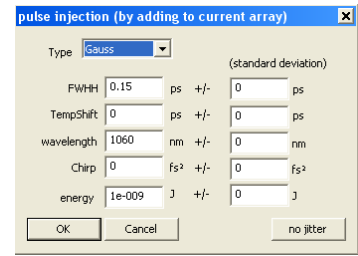
- q_0 – saturable reflectivity
- E_{sat} – saturation energy
- $A(t)$ – field envelope in $[J^{1/2}]$
- $q(t)$ – response of SESAM

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”

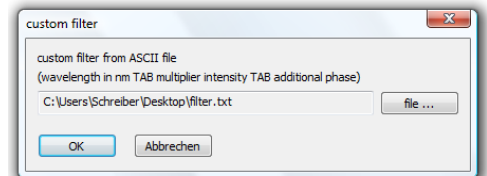
By this method a pulse is added to the current data array with randomly varying parameters according to the setup dialog. (Tip: In a multi-element propagation, add a high loss before this element to approximately zero the array and inject a pulse.)



“custom filter”

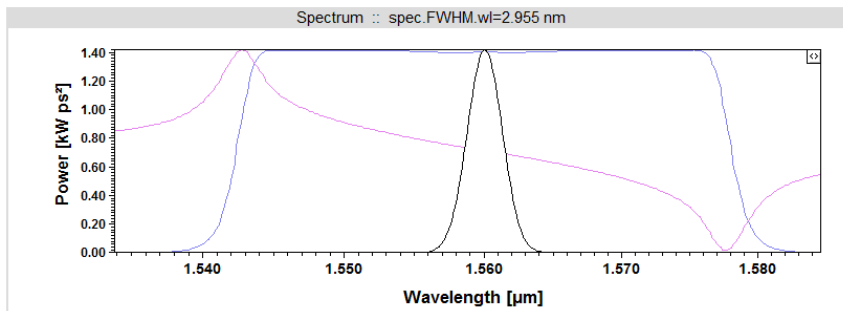
This allows to select an ASCII file with a custom defined transmission $T(\omega)$ for the spectral intensity and an additional spectral phase $\varphi(\omega)$. It is combined with the spectral field amplitude as follows:

$$\tilde{A}(\omega) \rightarrow \sqrt{T(\omega)} \cdot \tilde{A}(\omega) \cdot e^{i\varphi(\omega)}$$



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 “,”.

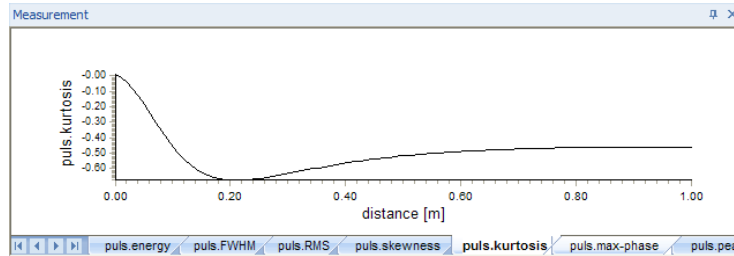
The imported data are displayed in the main view (normalized).





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.



Double click the window to copy the content of the current graph to the clipboard in ASCII format (three columns).

3.2.4. OUTPUT

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

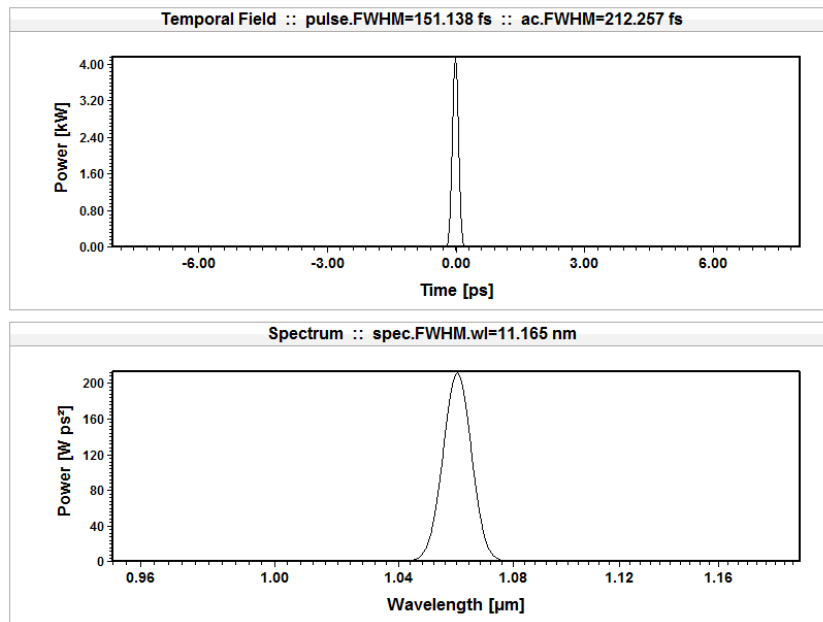




3.3. VIEW INTERFACE

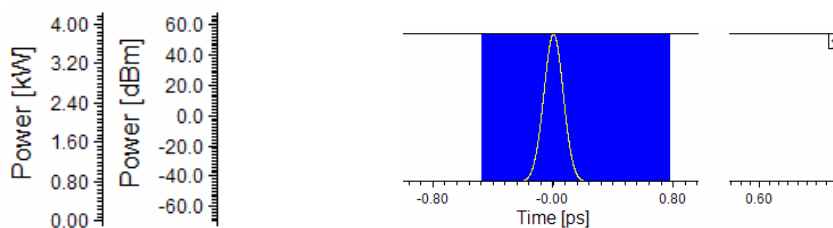
3.3.1. GENERAL VIEW

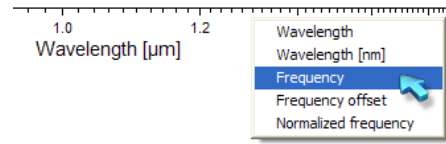
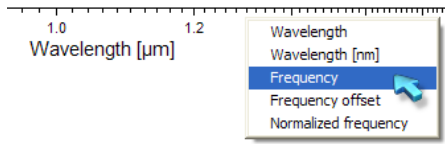
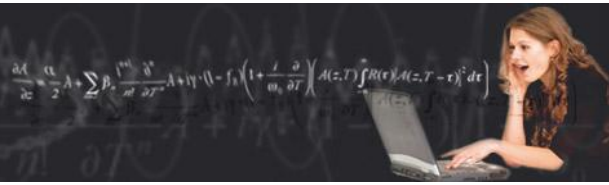
The general view can contain different views of the current electric field: the temporal field, its Fourier transformation as the spectral field and the autocorrelation. Each view can be independently switched on and off (see ribbon control “View”).



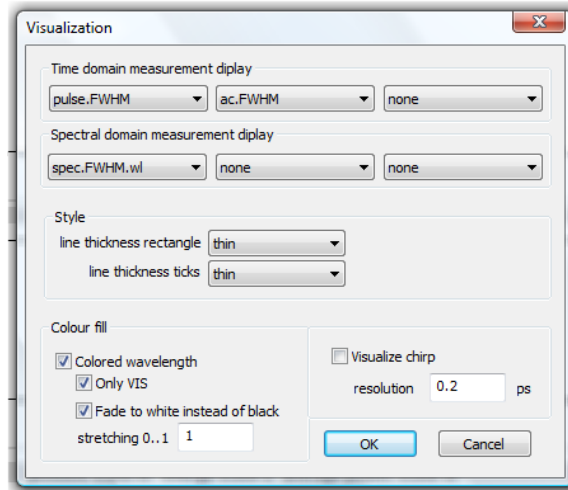
Control of the temporal and spectral view:

- 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:

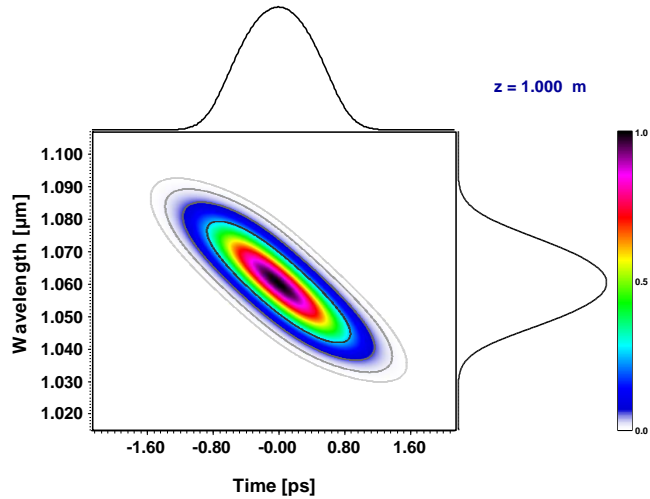
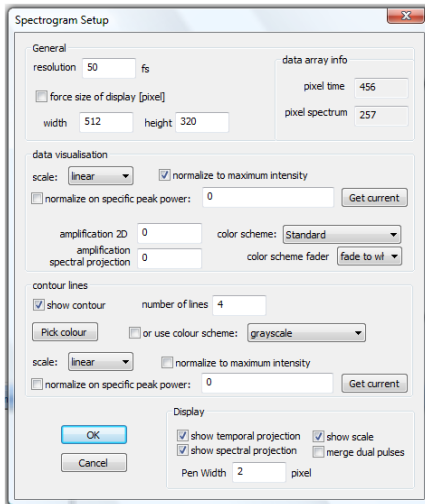
$$S(t, \lambda) = \left| \int_{-\infty}^{\infty} e^{-i\frac{c}{\lambda}\tau} e^{-i(\tau-t)^2/T_{BW}^2} A(z, \tau) d\tau \right|^2$$

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 amplifiers," *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)