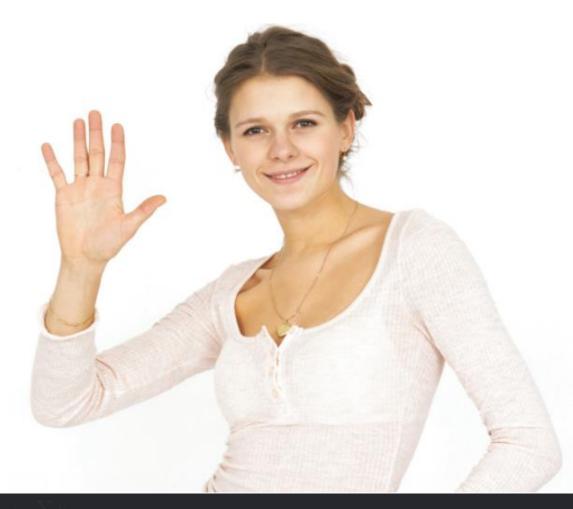
**Multi-Element Propagation** 

**Part 1:** Short Pulse Fiber Laser ... 2

Part 2: Mamyshev Oscillator ... 22

Part 3: Micro Comb Generator ... 30



#### Multi-Element Propagation: Example: Short Pulse Fiber Lasers

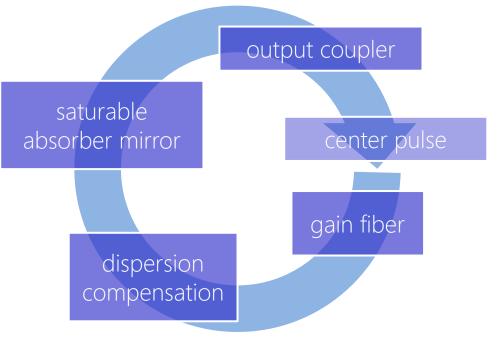
The layout of a typical short pulse oscillator (not only fiber laser) is shown in the image containing several elements in a ring cavity format (loop).

Each Element is modelled by an element typically based on the NLSE:

$$iA_{z} + \frac{g}{2}A + i\beta_{2}A_{tt} = i\gamma |A|^{2}A$$

Other elements, like the saturable absorber mirror is modelled by a fast saturable reflectivity/transmission according to:

$$R = R_{unsat} + R_{sat} \cdot \left(1 - \frac{1}{1 + P / P_{sat}}\right)$$



Each element setup is explained in the following >>

Multi-Element Propagation: Example: Short Pulse Fiber Lasers

Set up the gain fiber as a standard propagation with saturable gain

	١,	loss	0	1/m	
ain ×		gain	6.90776	1/m	
gain profile       add second peak         Center       1060       nm         Width ~ 40       nm       Width ~ 40       nm         shape       Gauss       shape       const       ratio of second to first peak (set to zero for only one peak):		MFD gamma Esat simulation		μm 1/(W m) μJ Raman	
gain saturation 1e-11 J $g = g_0 / (1 + E / E_{sat.gain})$		🗸 spm	× self-st	eepening	
user defined gain file         use ASCII file for gain profile given in g(1/m) vs. wavelength (separator TAB)         file         OK       Cancel         Copy shape to clipboard		paramet <b>x</b> temp steps stepsize distance	poral gain satu	100 0.01 m	
		distance		1.0 m	E

output coupler

Propagation parameter ×

standard propagatio

waveguide

center pulse

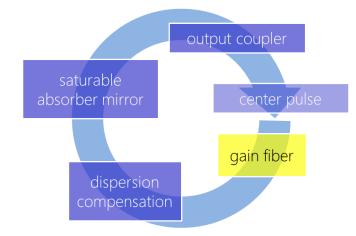
gain fiber

saturable

absorber mirror

dispersion compensation

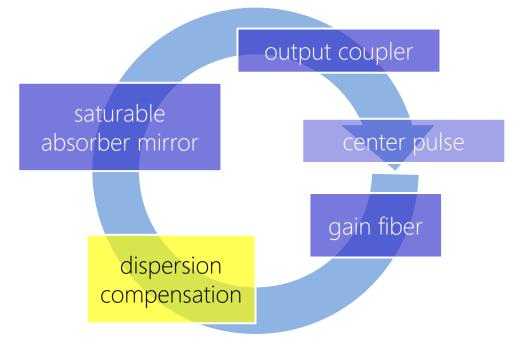
Multi-Element Propagation: Example: Short Pulse Fiber Lasers



#### Set the dispersion of that amplifier fiber to fused silica (e.g. predefined with its Taylor series at 1060 nm)

	ue	Dispersion Se	etup					4	
save as fiber.ppf	10 m 10 m 4 dispersion term	Taylor S Beta1		nm ps/m	predefi		more fused silica @1060nm KKT (core 1.7 µm zD=770,1250) @ 1030n NKT (core 1.7 µm zD=750,1600) @ 1030n		
← ☐ New	$\frac{\partial A}{\partial z} = \dots + \sum_{n \ge 1} \beta$	Beta2 Beta3 Beta4 Beta5 Beta6	0.01640341019153872 4.427598189728069e-5 -6.11686e-08 2.00994e-10 -6.78474e-13	ps³/m	5	-27.499385294 0.176321 00 400	air silica approx@780nm air silica approx@1660nm (1.7µm=MFD 1. air silica approx@1060nm (3.5µm=MFD 2. air silica approx@1060nm (5.0µm=MFD 4. NKT LMA 5 (5.0µm=MFD 3.5ym, 72b=103 NKT LMA 5 (5.0µm=MFD 4.2µm, 72b=1070 air silica approx@800nm (1.7µm=MFD 1.7 air silica approx@800nm (2µm=MFD 2µm) 720 approx@800nm (2µm=MFD 2µm) 720	.9µm) 2D@975nm .2µm) 2D@1060nm 55nm) @ 1030nm 0nm) @ 1030nm 2µm) 2D@665nm ) 2D@770nm @743nm	
C Load (Field and Multi-Element Settings) 호 Save (Field and Multi-Element Settings)	dispersion model ☐ ☐ ☐ Taylor expansion series ☐ Sellmeier coefficients	Beta7 Beta8 Beta9	2.11068e-15 -1.15713e-17 1.21432e-19			( [   	Damian @750nm,1600nm (MFD 1.6µm) Zl Cristiani et.al. Opt.Exp.12, 124 (2004)(MF) Judley et.al. Rev. Mod. Phys., Vol. 78, No. Layertech GTI 1000-1080nm - 250fs @103 Hollow core 1060-02@1030nm Zero dispersion @ all	D=3.47µm)ZD@710nm . 4, (2006) Fig. 3	
Save As	photonic crystal fiber gas-filled silica-hollow c	Beta10 Beta11 Beta12	-9.78137e-22 5.06311e-24 -1.65466e-26		force ret	tarded time frame	e (beta0=beta1=0)		
Recent	□ force retarded time frame (t ✓ Use dispersion	Beta13 Beta14	3.16819e-30 -2.74483e-33					max 2400	
Load propagation parameter <u> </u>	)5 0 -0.02 -	grating OK	g compressor >> Cancel		Save		copy dispersion ([nm],D[ps/nm/km],b2[ps²/m]) copy beta2 + group delay [nm],b2 [ps²/m], GD[ps/m]	1.12	1.19

Multi-Element Propagation: Example: Short Pulse Fiber Lasers

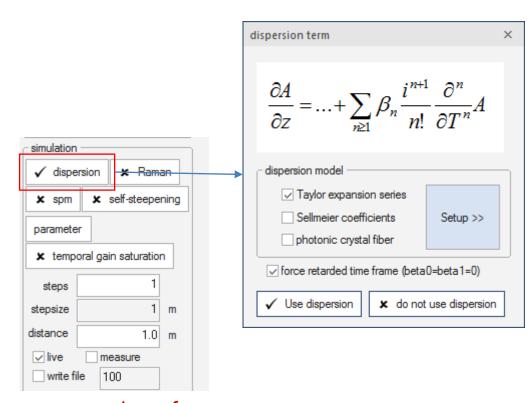


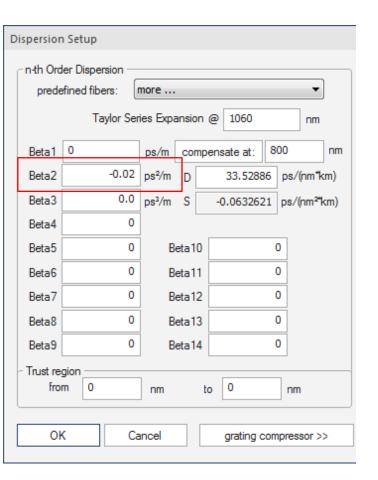
For the dispersion compensation, we only set second order dispersion.

Before, set the gain to zero, switch off SPM etc. Only dispersion need to be set.

As it is a linear step, a single step is enough, see next slide.

#### Multi-Element Propagation: Example: Short Pulse Fiber Lasers





saturable

absorber mirror

dispersion compensation

#### save as dc.ppf

output coupler

center pulse

gain fiber

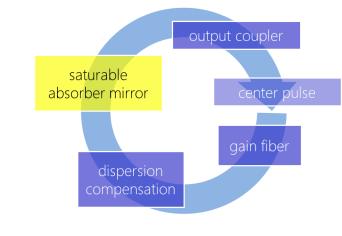
Multi-Element Propagation: Example: Short Pulse Fiber Lasers

The saturable absorber is a different model, select "saturable absorber" on top of the propagation parameter dialog.

Then, set it up with the parameters on the right.

Propagation parameter ×
saturable absorber 👻 Setup >
waveguide

save as SA.ppf



Saturable Loss		×
<ul> <li>✓ Fast saturable loss</li> <li>R0 70 %</li> <li>dR 30 %</li> <li>PA 100 W</li> </ul>	$R = R_0 + \Delta R - \frac{\Delta R}{1 + \frac{ A(T) ^2}{P_A}}$	OK Cancel
saturable absorber m	irror with time constants	
unsaturated reflectivity	60 % temporal response	A 0.2 ps
saturable reflectivity	30 %	
saturation fluence	30 µJ/cm²	
focal spot diameter	10 µm	
saturation energy	0.062831852 nJ	
use R=R0+dR*sin?	(Pi/2)*(P/PA)+phi_0) dR 30 PA 1 phi	i_0 0

#### Multi-Element Propagation:

Example: Short Pulse Fiber Lasers

#### Outcoupling:

50% means complex multiplication with sqrt(0.5)

#### Propagation parameter

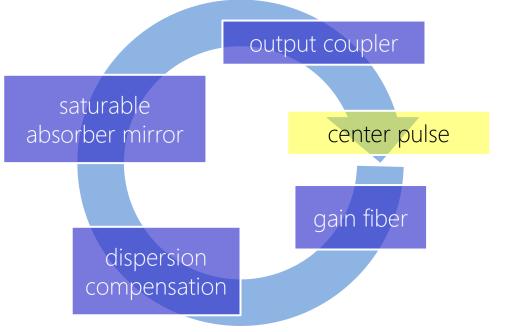
standard propagation	w.
standard propagation	
saturable absorber	
pulse injection	
custom filter	1
rate equation gain	d
pulse manipulation	
polarization manipulation	u
nonlinear loop mirror	
z-dependence	

		output coupler	
S	aturable		
absc	Manipulation	×	ulse
	<ul> <li>Create Pulse</li> <li>Center Pulse</li> <li>Create double pulse delay of pulses (will be</li> <li>✓ take phase shift into account (</li> <li>✓ Complex Multiplication Temporal t - time in sec helper variable h = 0</li> <li>sqrt(0.5)</li> <li>i 0</li> <li>Complex Multiplication Spectral I wl - wavelength in m, f - frequency helper variable h = 0</li> <li>1</li> <li>0</li> </ul>	I Domain	
	OK Cancel		

#### save as OC.ppf

#### Multi-Element Propagation: Example: Short Pulse Fiber Lasers

Manipulation >	ĸ
Center Pulse	
Create double pulse	
delay of pulses (will be centered) 0.0 ps take phase shift into account (Mach-Zehnder equivalent)	
Complex Multiplication Temporal Domain	Ì
i 1	
Complex Multiplication Spectral Domain	
i 1	
	J
OK Cancel	



- Center pulse in the time domain, helps to converge the pulse, as changes are measured in the time domain

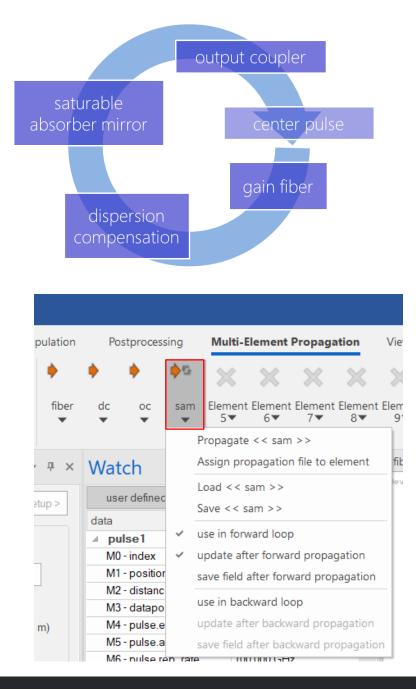
- Can be combined with OC.ppf in a single element

Propagation parameter >	<
pulse manipulation 👻 Setup >	
waveguide	
loss 0.7 + /	

#### save as center.ppf

#### Multi-Element Propagation: Example: Short Pulse Fiber Lasers

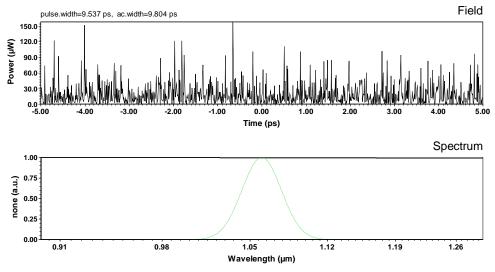
- assign all files to elements in the right order of the cavity
- Select "use in forward loop" for all elements
- Select the last one to be updated after each loop to see convergence live during simulation
- lcons on top change according to selected status



Multi-Element Propagation: Example: Short Pulse Fiber Lasers

(1) create initial pulse, e.g. quantum noise

#### (green spectrum is the gain spectrum from "fiber.ppf"

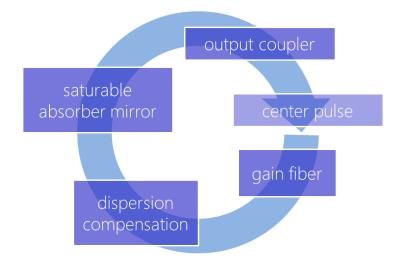


listance: 0.000 m position: 0.000 m energy: 191.864 aJ average power: 19.186 µW roundtrip: 0

Pulse Profile and Data Array	<u> </u>
⊂ data array setup	
Size 1k (2^10)	
1000	
array center wavelength 1060	
half intervall 5 🗘 ps	
field profile definition	
field profile definition	
Type Gauss -	
FWHM 1 🗘 ps	
TempShift 🛛 🛛 🗎 🗘 ps	
phase 0 _ rad	
wavelength 1060 🛟 nm	
2nd order spectral phase 0 + fs <sup>2</sup>	
3rd order 0 A fs <sup>3</sup>	
•	
energy 🗌 0 🏮 J	
average power 🗹 0 🗘 W	
repetition rate 1e+11 🗘 Hz 🗸 cw	
scramble spectral phase (random phase)	
phase diffusion modell with given linewidth	
$\checkmark$ add quantum noise (one photon per spectral node)	
double pulsing	
separation 0 ps magnitude 0	
✓ create field in data array 1	
add field to data array 1	
OK Apply Cancel reset	

#### Multi-Element Propagation: Example: Short Pulse Fiber Lasers

(1) start loop (switch on "write slice … " for later postprocessing)

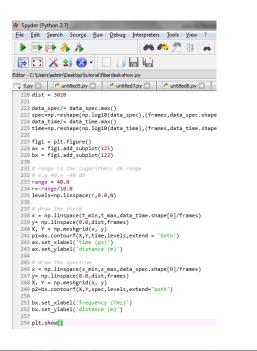


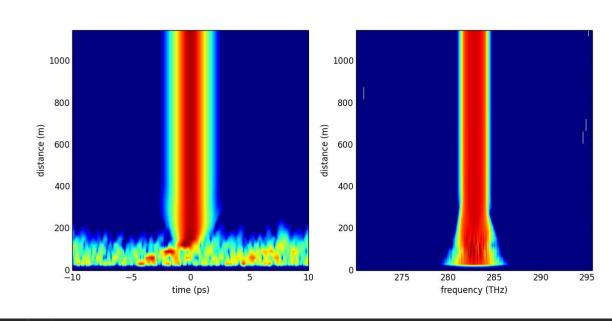


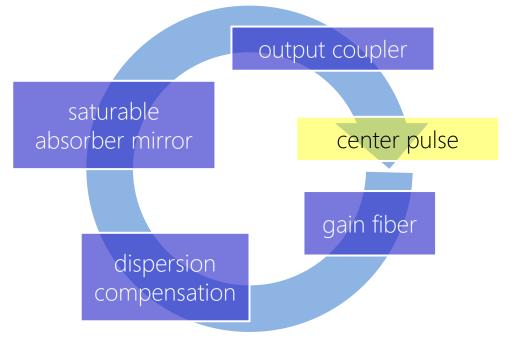
Loop propagation				×
✓ switch off individual □ update view after ea		2	5	5
vrite slice to bpf file		100		frames
maximum number of lo	oops	1000	)	
Automatic stop of loop	, — ·			
stop if converge	ed			
- condition	1- 00	~	1	-
minimum change of	1e-00	0		
for at least	10		loops	
ОК	C	ance	I	

#### **Multi-Element Propagation:** Example: Short Pulse Fiber Lasers

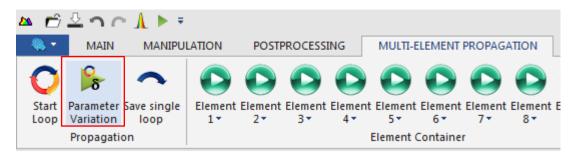
Download the python script from the homepage to process BPF files.







fiberdesk

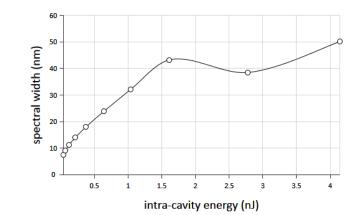


#### Multi-Element Propagation:

Example: Short Pulse Fiber Lasers

Multi-element > Parameter variation we change the gain saturation to increase the energy (remark: intracavity energy!)

2D use final field as	s input for next loop (otherwise use start/create field) = x J , with x 1e-011	to 1e-009	datapoints log steps
in Element 0 - fibe	x-axis value =	1e9*M2	
✓ save to file C:\Use	rs \admin \Desktop \tutorial \oscillator simulations \energy so	aling.pvf	select base file
	Result = 1e9*M20 update or	use M20 - spec.	width.m 👻
start multiple elements	auto axis x intra-cavity energy (nJ)		
setup >>	auto axis y spectral width (nm)		

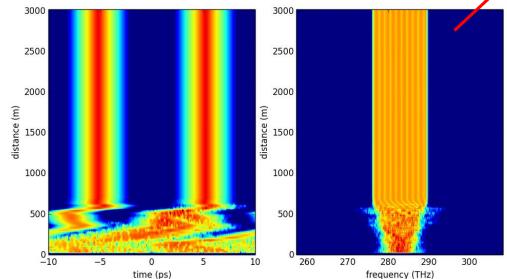


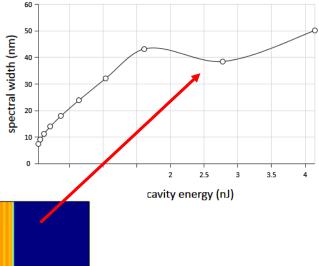


#### Multi-Element Propagation:

Example: Short Pulse Fiber Lasers

Multi-element > Parameter variation we change the gain saturation to increase the energy (remark: intracavity energy!)



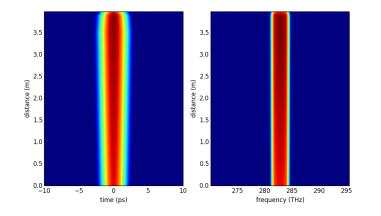


Multi-Element Propagation: Example: Short Pulse Fiber Lasers

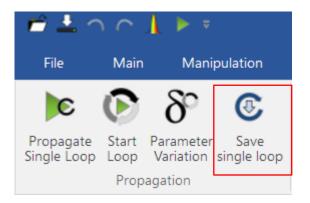
Intracavity evolution

- (1) select stable solution from saved file
- (2) specify slices to be saved
- (3) post-process

fiberdesk



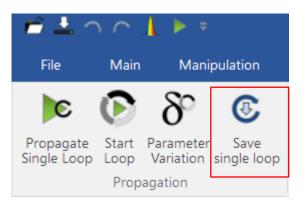
 $\frac{\partial \mathcal{A}}{\partial z} = \frac{\alpha}{2} \mathcal{A} + \sum_{i} \beta_{i} \frac{e^{i \theta_{i}}}{\sigma^{2}} \frac{\partial^{2}}{\partial z^{2}} \mathcal{A} + i\gamma \cdot (1 - f_{1}) \left(1 + \frac{i}{\omega_{i}} \frac{\partial}{\partial T}\right) \left(\mathcal{A}(z, T) \int_{z}^{z} \mathcal{R}(\mathbf{r}) \mathcal{A}(z, T - \mathbf{r})^{2} d\mathbf{r} \right)$ 

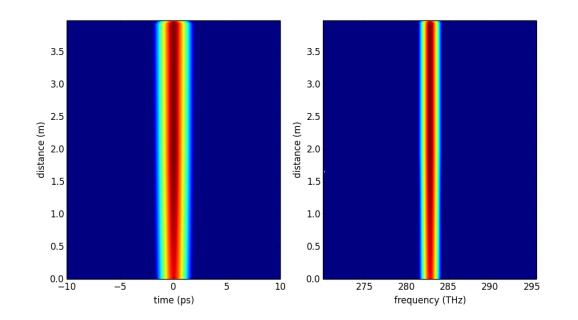


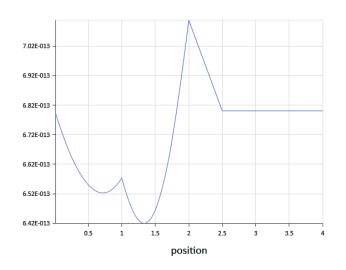
Dialog					3
forward	backward	filename	distance		slices
$\checkmark$		ons\fiber-simple.ppf	0	m	100
$\checkmark$		∙simulations\DC.ppf	0	m	10
$\checkmark$		simulations\SAM.ppf	0	m	1
$\checkmark$		simulations\OC.ppf	0	m	1
$\checkmark$		ulations\center.ppf	0	m	1
$\checkmark$			0	m	0
$\checkmark$			0	m	0
$\checkmark$			0	m	0
$\checkmark$			0	m	0
$\checkmark$			0	m	0
		s	um of slices:		113
		Cancel	Sav	e to B	PF file >>

Multi-Element Propagation: Example: Short Pulse Fiber Lasers

soliton solution:  $beta2@DC = -0.06 ps^2$ 

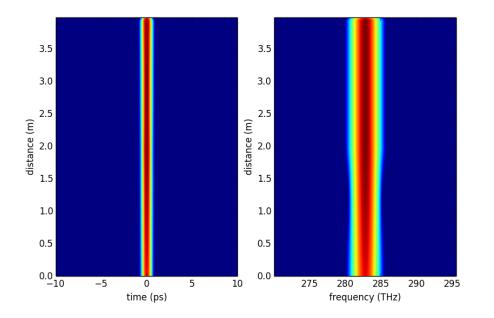


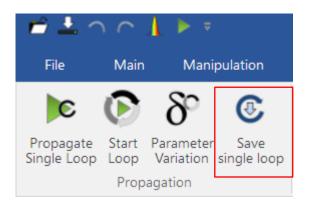


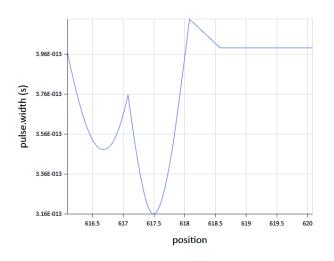


Multi-Element Propagation: Example: Short Pulse Fiber Lasers

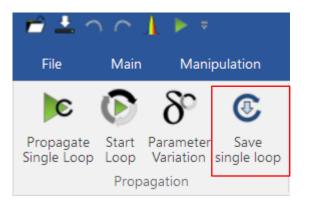
soliton solution: beta2@DC = -0.04 ps<sup>2</sup>



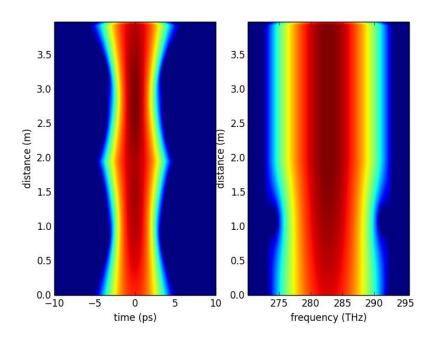


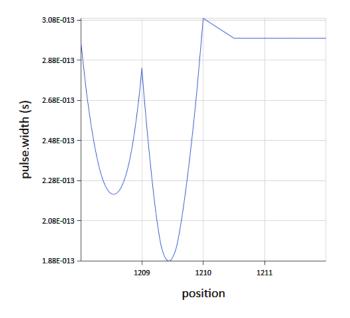


Multi-Element Propagation: Example: Short Pulse Fiber Lasers



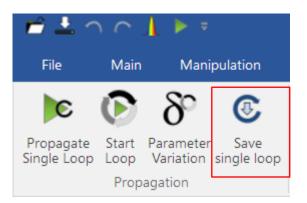
toward stretched pulse:  $beta2@DC = -0.03 ps^2$ 

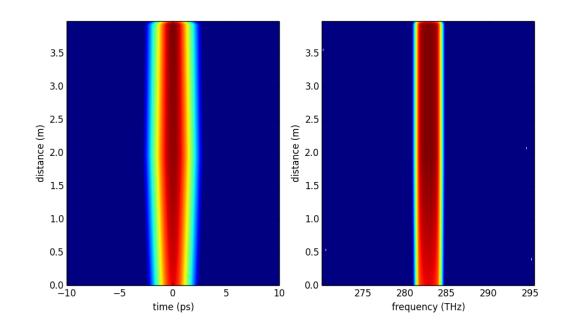


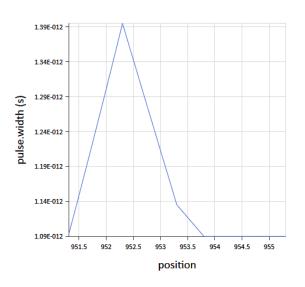


Multi-Element Propagation: Example: Short Pulse Fiber Lasers

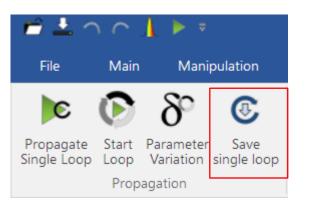
similariton: beta2@DC =  $-0.02 \text{ ps}^2$ 



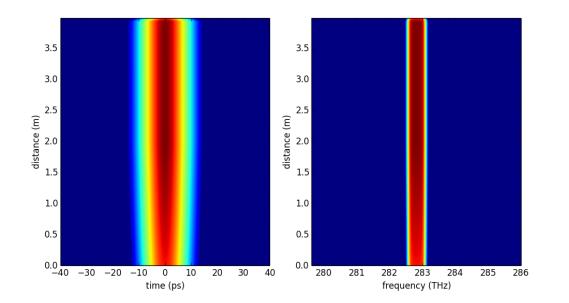


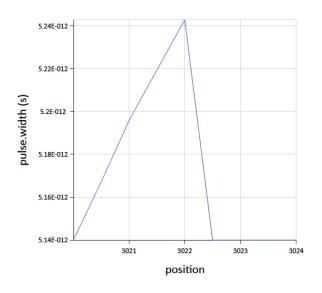


Multi-Element Propagation: Example: Short Pulse Fiber Lasers



chirped pulse oscillator:  $beta2@DC = +0.02 ps^{2}$ 





#### Part 2: Mamyshev Oscillator

See Z. Liu, Z. Ziegler, L. G. Wright, and F. W. Wise. "Megawatt peak power from a Mamyshev oscillator." Optica 4, 649 (2017).

#### The model of the Mamychev oscillator is using the following elements:



It uses two separated filters at 1030 nm and 1040 nm as well as passive and active fibers in between. The gain fibers are different after the filter. An output coupler is used at the end.

The filters are defined as follows:

#### Pulse manipulation propagation Saved as: 1040.ppf

Manipulation					×
Create Pulse					
change repetition rate to	0		Hz		
Create double pulse					
delay of pulses (will be		0.0		ps	
take phase shift into acco	ount (	Mach	Zehno	der equival	
Delay Pulse (temporal shift)		0.0		ps	
Center Pulse					
Complex Multiplication Temp	poral	Domai	n		
t - time in sec					
helper variable h	0				
sqrt(0.75)					
i 0					
✓ Complex Multiplication Spec	tral D	omain			
wl - wavelength in m, f - fre					
helper variable h	0				
sgrt(0.7*exp(-(wl-1040e-9)	^2/(4	le-9)^	2)^2)		
i 0	-/ (	- /	, -,		
0					
OK Cancel					

Contains a general loss of 25 % and a filter transmission of 70%. The width  $(1/e^2)$  is 4 nm centered at 1040 nm.

### Pulse manipulation propagation Saved as: 1030.ppf

Manipulation	×
Create Pulse	
change repetition rate to 0	Hz
Create double pulse	
delay of pulses (will be	0.0 ps
✓ take phase shift into accoun	at (Mach-Zehnder equival
Delay Pulse (temporal shift)	0.0 ps
Complex Multiplication Tempora	al Domain
t - time in sec	
helper variable h	0
sqrt(0.75)	
i O	
Complex Multiplication Spectral	Domain
wl - wavelength in m, f - frequ	ency in Hz
helper variable h	0
sqrt(0.7*exp(-(wl-1030e-9)^2	/(4e-9)^2)^2)
i 0	
OK Cancel	

Similar, but centered at 1030 nm.

The passive fiber is defined as a standard propagation. The dispersion is only second order at 1035 nm.

#### standard propagation Saved as: passive.ppf

Propaga	ation parameter	•	푸 × Watch 🔹 푸 ×
standard p	ropagation	Setu	dispersion term
waveguid	de		$\partial A = i^{n+1} \partial^n = beta 0$
loss	0.0	1/m	$\frac{\partial A}{\partial t} = \dots + \sum \beta \frac{l}{\partial t} \frac{\partial A}{\partial t} = \frac{\partial A}{\partial t}$
gain	0	1/m	$\frac{\partial A}{\partial z} = \dots + \sum_{n \ge 1} \beta_n \frac{i^{n+1}}{n!} \frac{\partial^n}{\partial T^n} A \xrightarrow[beta 1]{beta 1} $
MFD	10	μm	
gamma	0.00248543689320388	1/(W n	OZ $n \ge 1$ $n:$ OI     beta 2       idispersion model $\checkmark$ D $\checkmark$ D $400$ $600$ $800$ idispersion model $\checkmark$ Taylor expansion series $\bigcirc$ Setup >> $\bigcirc$
Esat	23.561	μJ	✓ Taylor expansion series
simulatio	rsion ✓ Raman / TPA ✓ self-steepening		Sellmeier coefficients       Setup >>         photonic crystal fiber       -0.5         gas-filled silica-hollow core fiber       -1         force retarded time frame (beta0=beta1=0)         ✓ Use dispersion       × do not use dispersion       auto y       min       -1       max       1
ster	ns.	100	Dispersion Setup
stepsi;		0.008	Taylor Series @ 1035 nm predefined more *
distand		0.8	
measu write fi	ure and parse		Beta1 0 ps/m compensate at: 800 nm
			Beta2         0.02         ps²/m         D         -35.168177876t         ps/(nm*km)           Beta3         0.0         ps³/m         S         0.0679578         pc/(nm²km)
	aptive 6e-07 I error		
	presets: *		Trust region
random	temporal clipping		Trom 0 nm to 2000 nm
			Beta6

The output coupler is again defined as a pulse manipulation:

#### Pulse manipulation propagation Saved as: OC1.ppf

Manipulation	×
Create Pulse	
change repetition rate to 0 Hz	
Create double pulse	
delay of pulses (will be 0.0 ps	
✓ take phase shift into account (Mach-Zehnder equival	
□ Delay Pulse (temporal shift) 0.0 ps ✓ Center Pulse	
Complex Multiplication Temporal Domain	
t - time in sec	
helper variable h 0	
sqrt(0.5)	
i O	
Complex Multiplication Spectral Domain	
wl - wavelength in m, f - frequency in Hz	
helper variable h 0	
0	
i O	
OK Cancel	

50% Transmission.

#### Pulse manipulation propagation Saved as: OC2.ppf

Manipulation	×
Create Pulse	
change repetition rate to 0 Hz	
Create double pulse	
delay of pulses (will be 0.0 ps	
✓ take phase shift into account (Mach-Zehnder equival	
□ Delay Pulse (temporal shift) 0.0 ps ✓ Center Pulse	
<ul> <li>Complex Multiplication Temporal Domain</li> <li>t - time in sec</li> </ul>	
helper variable h 0	
sqrt(0.12)	
i 0	
Complex Multiplication Spectral Domain	
wl - wavelength in m, f - frequency in Hz	
helper variable h 0	
O	
i O	
OK Cancel	

#### 12% Transmission. (88% out-coupling)

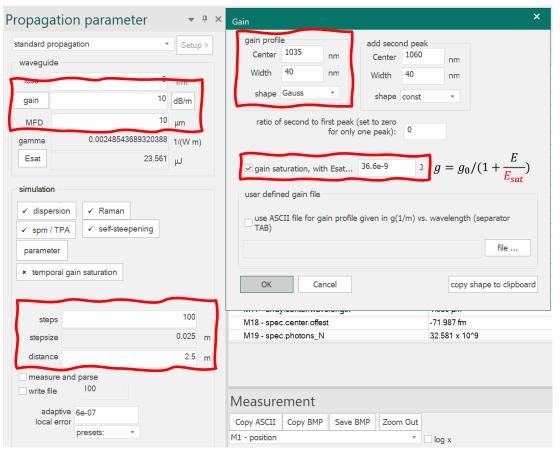
The first gain fiber is defined as a standard propagation:

#### Standard propagation Saved as: gain1.ppf

Propagation para	ameter 🔹	Ψ×	Gain					×
standard propagation waveguide iese gain MFD gamma 0.002 Esat simulation	<ul> <li>Setu</li> <li>10</li> <li>48543689320388</li> <li>1/(W m 23.561</li> <li>μJ</li> </ul>		Width shape ratio of	1035 40 Gauss second to first turation, with	nm C nm W st peak (set to for only one p	eak): 0	nm nm	$/(1+\frac{E}{E_{sat}})$
<ul> <li>✓ dispersion</li> <li>✓ Ra</li> <li>✓ spm / TPA</li> <li>✓ sel</li> <li>✓ parameter</li> <li>✓ temporal gain saturation</li> </ul>	f-steepening			-		n in g(1/m) vs.		(separator file
steps stepsize distance	100 0.025 2.5	m m	M18 - spec	.center.offest .photons_N	ongu.		-71.987 fm 32.581 x 10	^9
write file 100 adaptive 6e-07 local error presets: random temporal clippir	×		Measure Copy ASCII M1 - position M0 - index	Ment <sub>Copy BMP</sub>	Save BMP	Zoom Out *	log x log y	

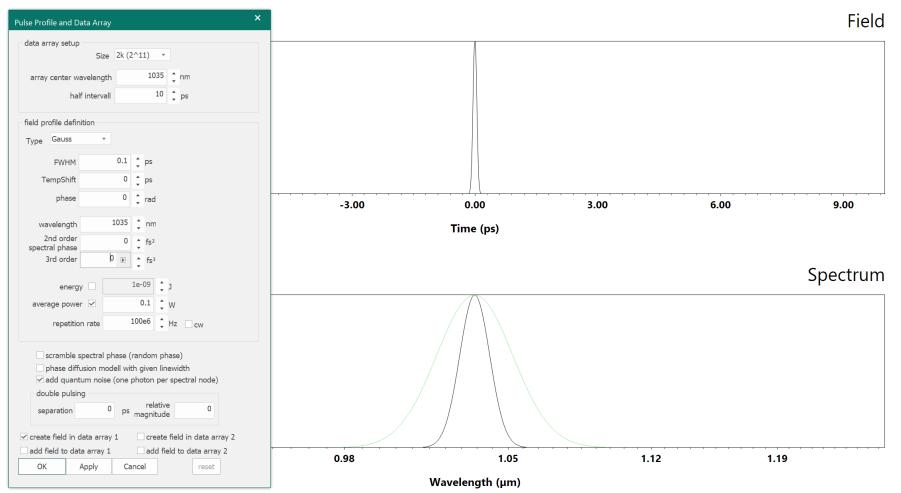
The second gain fiber is defined as a standard propagation:

#### Standard propagation Saved as: gain2.ppf

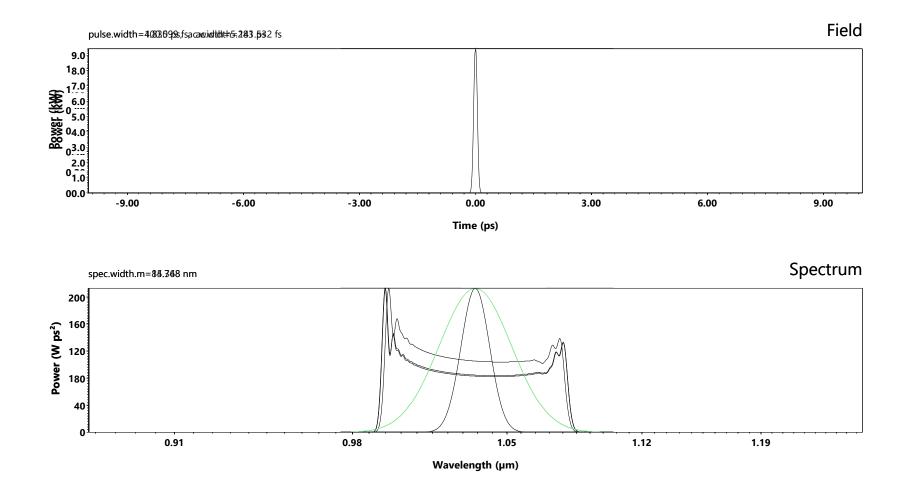


As most Mamychev oscillators are not self starting, we seed with a short pulse:

#### **Create Pulse:**



After some roundtrips, we see the pulse converging. However, after many roundtrips, the pulse might destabilize.



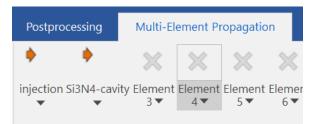
#### Part 3: Micro Comb Generator

Alessia Pasquazi, Marco Peccianti, Luca Razzari, David J. Moss, Stéphane Coen, Miro Erkintalo, Yanne K. Chembo, Tobias Hansson, Stefan Wabnitz, Pascal Del'Haye, Xiaoxiao Xue, Andrew M. Weiner, Roberto Morandotti, Micro-combs: A novel generation of optical sources, Physics Reports, Volume 729, 2018, Pages 1-81.

Fiberdesk's multi element propagation can be used to simulate roundtrips in the micro-resonator. Please see section 5.1 of the reference for details. In principle, the first element simulates the in/outcoupling (boundary conditions) and the second element is the nonlinear propagation within the resonator.

$$E^{(m+1)}(0,\tau) = \sqrt{\theta} E_{\text{in}} + \sqrt{1-\theta} E^{(m)}(L,\tau) e^{i\phi_0},$$
  
$$\frac{\partial E(z,\tau)}{\partial z} = -\frac{\alpha_i}{2} E + i \sum_{k\geq 2} \frac{\beta_k}{k!} \left(i\frac{\partial}{\partial \tau}\right)^k E + i\gamma |E|^2 E$$

So, only two elements need to be defined:



Please also note that the average propagation equation (LLE) can be used for simulating Micro Comb Generation but are intended for another tutorial.

The injection element is done using the "pulse injection" propagation. As you can see, in the setup a low transmission (High Q Cavity) and long pulse duration (to simulate a cw injection) is given.

#### Save as injection.ppf

ropag	ation param.	▼ <sup>∓</sup> ×	pulse injection (by ad	ding to curre	ent a	rray)			)
oulse inje	ction •	Setup >							
wavegui	de			$E_{out} = \sqrt{T \cdot E_i}$	n +√	$\overline{1-T} \cdot E_0$			
loss	0.0	1/m							
gain	0	1/m	$E_{in}$ $\Box$ $E_0$						
MFD	3	μm							
gamma	0.026834381551362	1/(W m)	E_0 - existing field		у	transmi	ssion T 0	.1	%
Esat	2.1205	μJ	E_in - defined belo E_out - interfering f			phase	e phi_0		rad
simulatio	n		Type Gau	SS >>					
🗸 disp	ersion × Raman								
✓ spm	/TPA × self-stee	pening	FWHH	1e6	ps	+/-	0	ps	
parame	ter		TempShift	0.0	ps	+/-	0	ps	
× tom	ooral gain saturation		wavelength	1550	nm	+/-	0	nm	
- temp			Chirp	0.0	fs²	+/-	0	fs²	
			energy	0.001e-9	J	+/-	0	J	
ste		10	ОК	Cancel				zero dev	/iations
stepsi	ze 0.000599	584916 m							

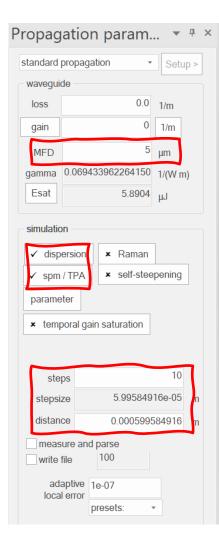
The ring itself is defined as a standard propagation with the dispersion of the material (including the waveguide dispersion), the nonlinearity and length.

The dispersion is a simple second order approx. only.

#### Save as Si3N4-cavity.ppf

dispersion term	, and the second se				
$\partial A$ , $\sum a^{i}$	$n^{n+1} \partial^n$	Dispersion Setu	0		
$\frac{\partial A}{\partial z} = \dots + \sum_{n \ge 1} \beta_n \frac{i}{z}$	$\overline{n!} \ \overline{\partial T^n}^A$	Taylor Seri	es @ 155	0	nm
dispersion model		Beta1	ſ	0	ps/m
✓ Taylor expansion series		Beta2		-0.02	ps²/m
_ / /	Setup >>	Beta3	-	0.0	ps³/m
Sellmeier coefficients	ootup	Beta4		0	
photonic crystal fiber		Beta5		0	
gas-filled silica-hollow core fit	Der	Beta6		0	
		Beta7		0	
✓ force retarded time frame (beta	0=beta1=0)	Beta8		0	
✓ Use dispersion × do	not use dispersion	Beta9		0	

self phase mod	ulation / two photon absc	orption term
$\frac{\partial A}{\partial z}$	$= \cdots + i\gamma(1 -$	– <u>f</u> <sub>R</sub> )A(T)
$\gamma = \frac{1}{2}$	$\frac{\omega_0}{c} \frac{n_2}{A_{\text{off}}}$ and $A_{\text{eff}}$	$f_{\rm f} = \frac{\pi}{4} MFD^2$
n2		2.3e-19 m²/\/
fR		0.15
ТРА		0 m/W
TPA is exp	erimental so far	
saturate		1.0 GW/cm <sup>2</sup>
✓ use SPM	and TPA	★ exclude SPM



Starting the multi-element propagation. (Please make sure to have done the first steps of this tutorial to learn multi-element propagation.)

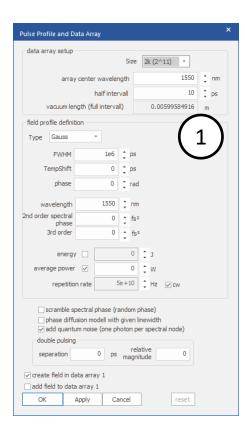
Quick reminder:

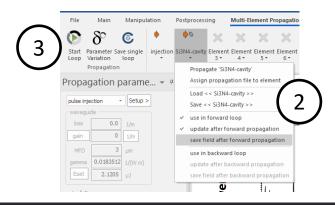
- Setup a field with a temporal window fixed to the length of the cavity (here ~60µm). This allows to draw a roundtrip map later on. We also only use quantum noise as the input come from the injected field.
- (2) Assign the two propagations files to elements and use both in forward loop direction. Also, to see the chance after the propagation, switch on "update after forward propagation" of the second element. You might also save the field after forward propagation, in order to postprocess it later on, e.g. plot te graph on the next slide.
- (3) Setup and start the loop.

fiberdesk

 $\frac{\partial A}{\partial z} = \frac{\alpha}{2} A + \sum \beta_{+} \frac{1}{\alpha'} \frac{\partial}{\partial z'} A + i\gamma \cdot (1 - f_{+} \left(1 + \frac{i}{\omega_{+}} \frac{\partial}{\partial T}\right) A(z,T) \int R(z) A(z,T-z)_{i} dz$ 

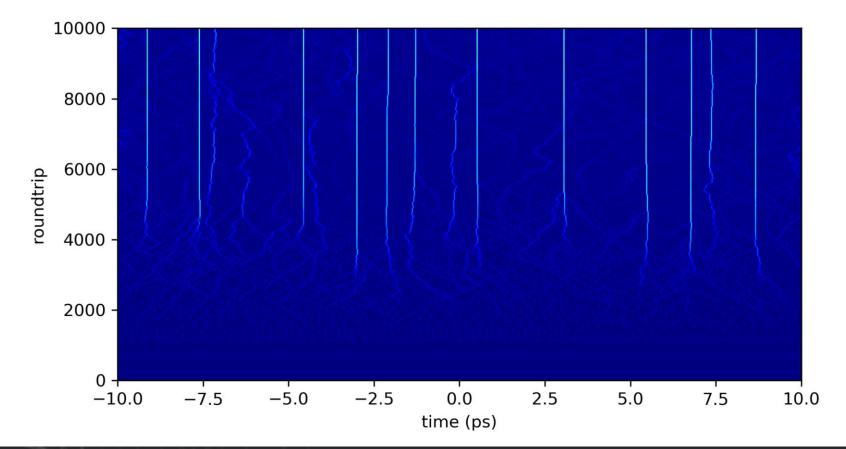






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Using the python script, you can draw the save file and get this roundtrip map. It shows the built-up of structures from the cw input. The parameters now need to be refined to enable the desired output.



 $\begin{array}{l} \textbf{fiberdesk} \\ \textbf{fiberdesk} \\$