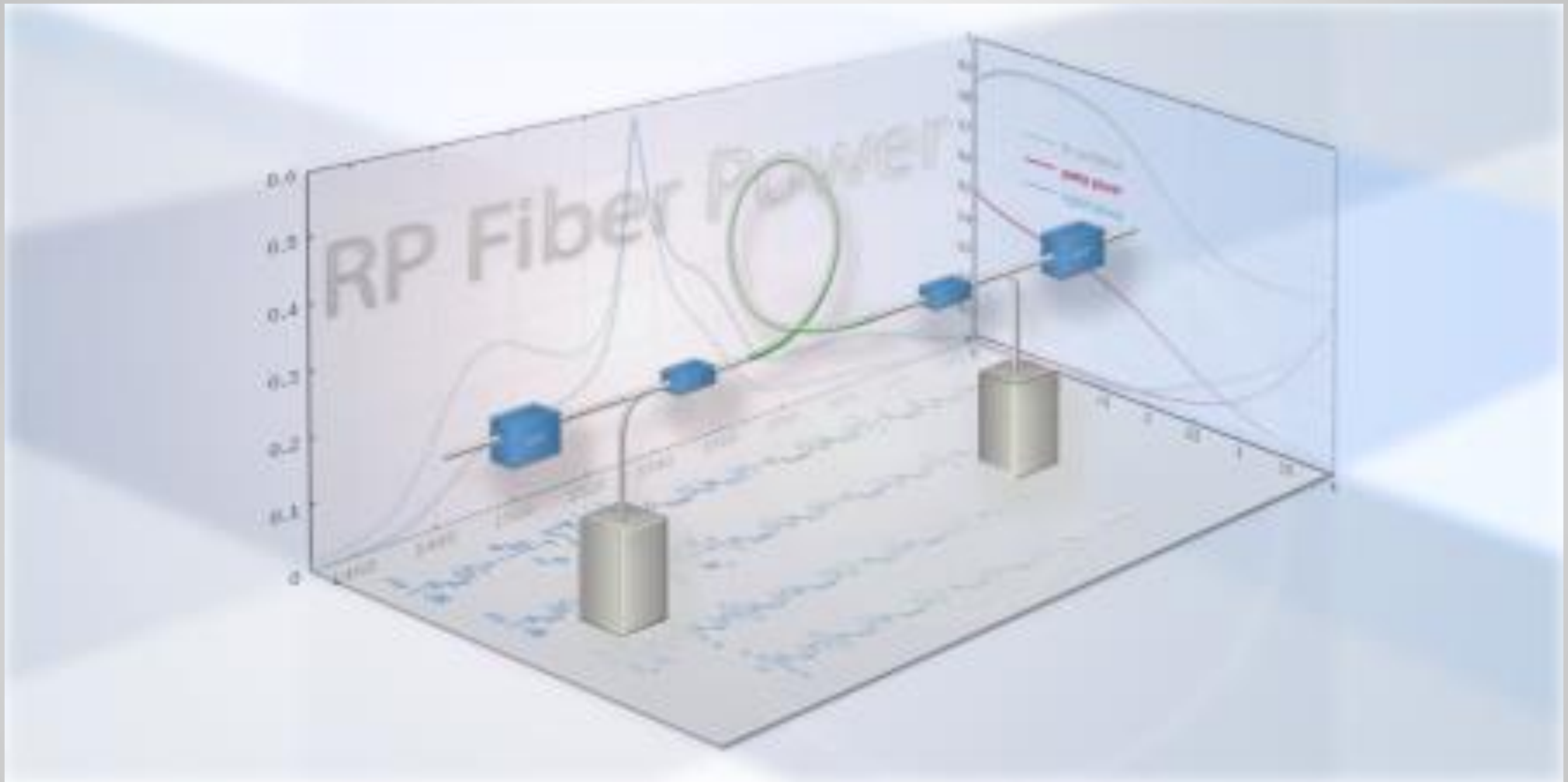
RP Fiber Power V8



a software product of

RP Photonics AG

www.rp-photonics.com/rp_fiber_power.html

What are Simulations in Fiber Optics Good For?

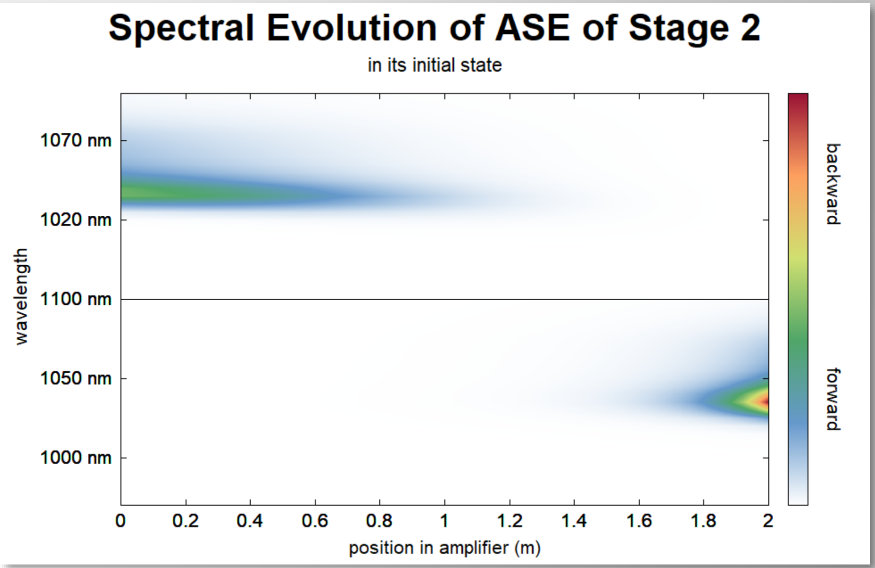
- Develop a quantitative understanding of your devices.
- Understand performance limitations and find optimized device designs.
- Thoroughly check designs before buying the parts and building a prototype or an improved version.
- Find out the cause of unexpected behavior.
(Experiments often don't tell you *why* it doesn't work.)
- Get inspired for new ideas when playing with a model.

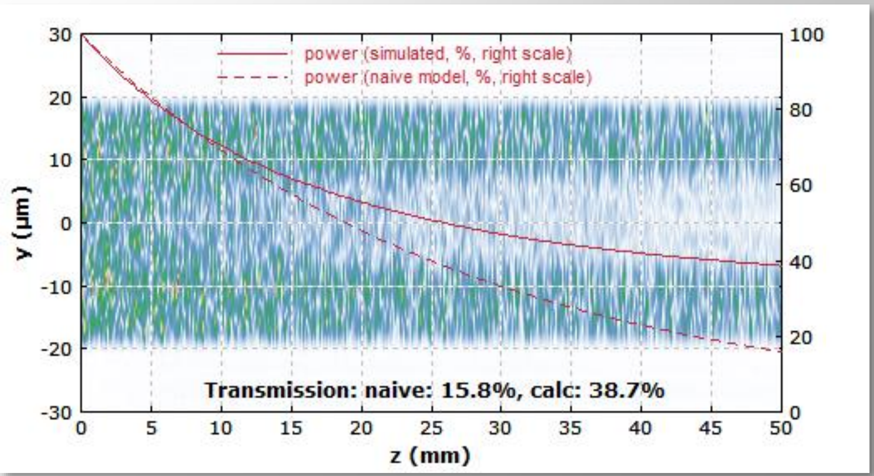
- **Get better results in your R&D work**
while speeding it up and reducing the cost.

Profit From Powerful Software

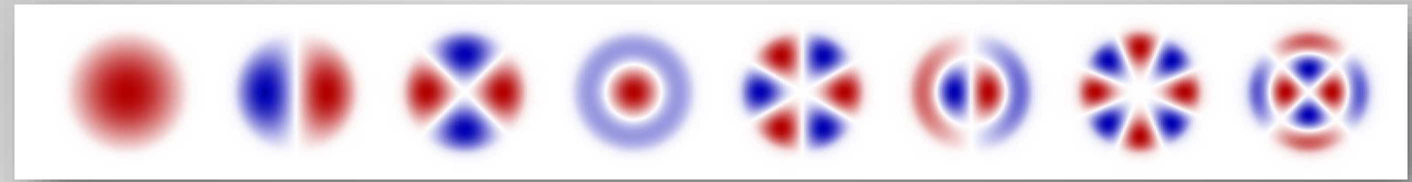
- Get all relevant calculations done, e.g. involving fiber modes, power propagation, full beam propagation, ultrashort pulses, laser dynamics, etc.
- Easily work with a graphical user interface, *but without being limited by a fixed set of forms*!
- Enjoy high-quality comprehensive documentation.
- Get reliable results and competent technical support from a top expert in the field.

- **RP Fiber Power offers all that.**
  It is the industry-leading solution.





Calculation of Fiber Modes (1)

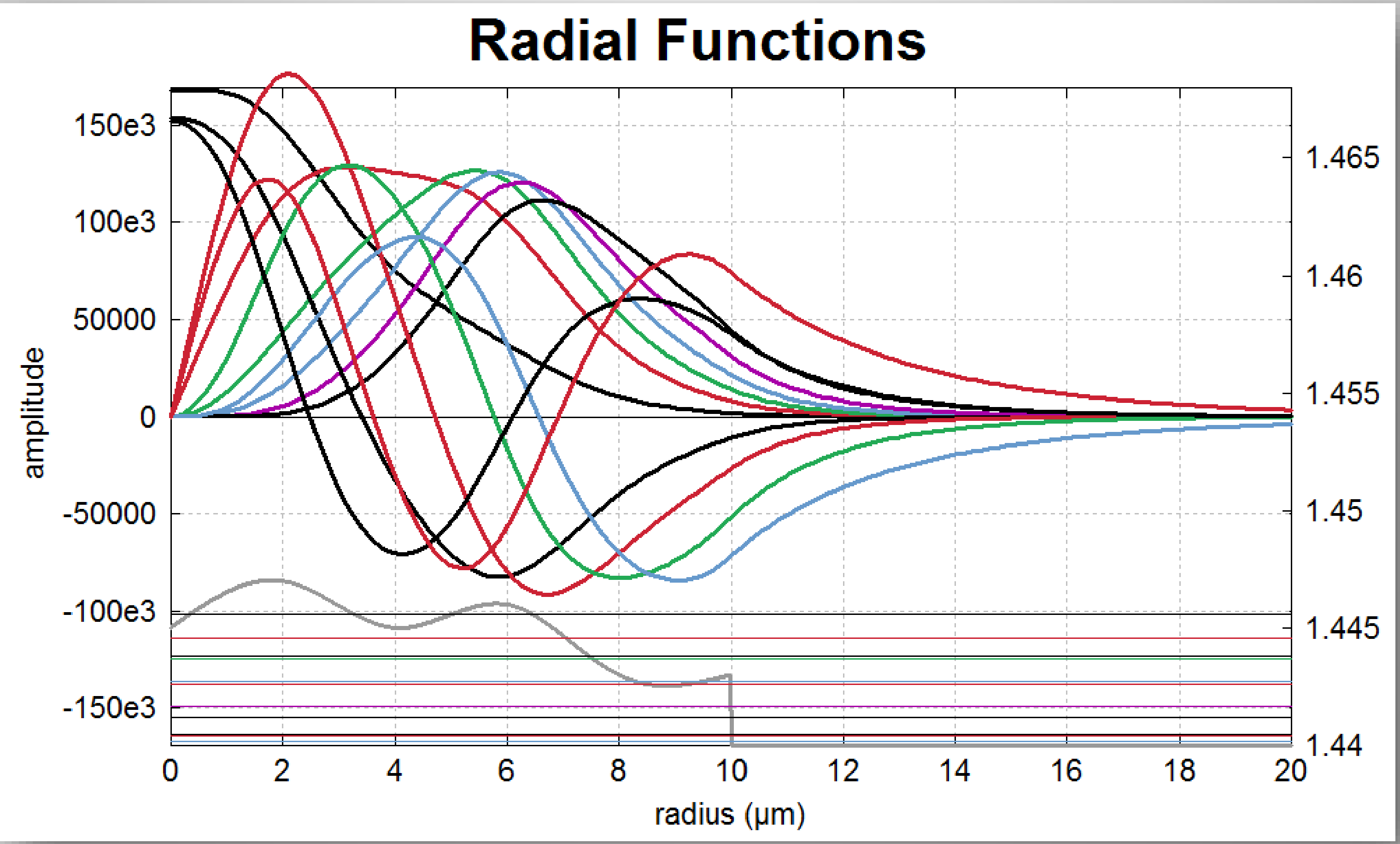


From a given refractive index profile, the integrated mode solver calculates all guided modes (LP modes):

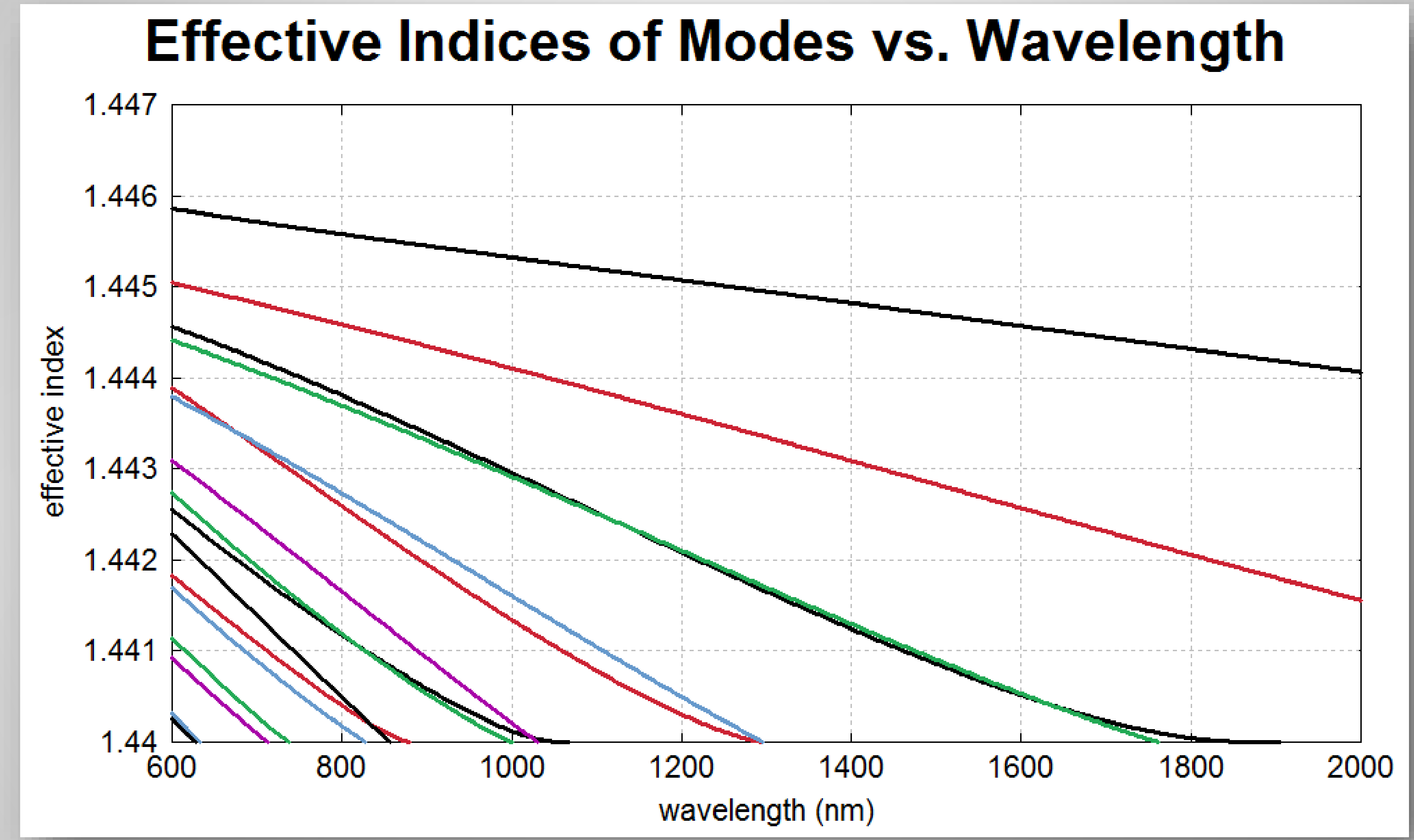
- amplitude and intensity profiles
- effective mode areas
- cut-off wavelengths
- effective refractive indices and group indices
- chromatic dispersion

- Index profiles can have any radial dependence and wavelength dependence.

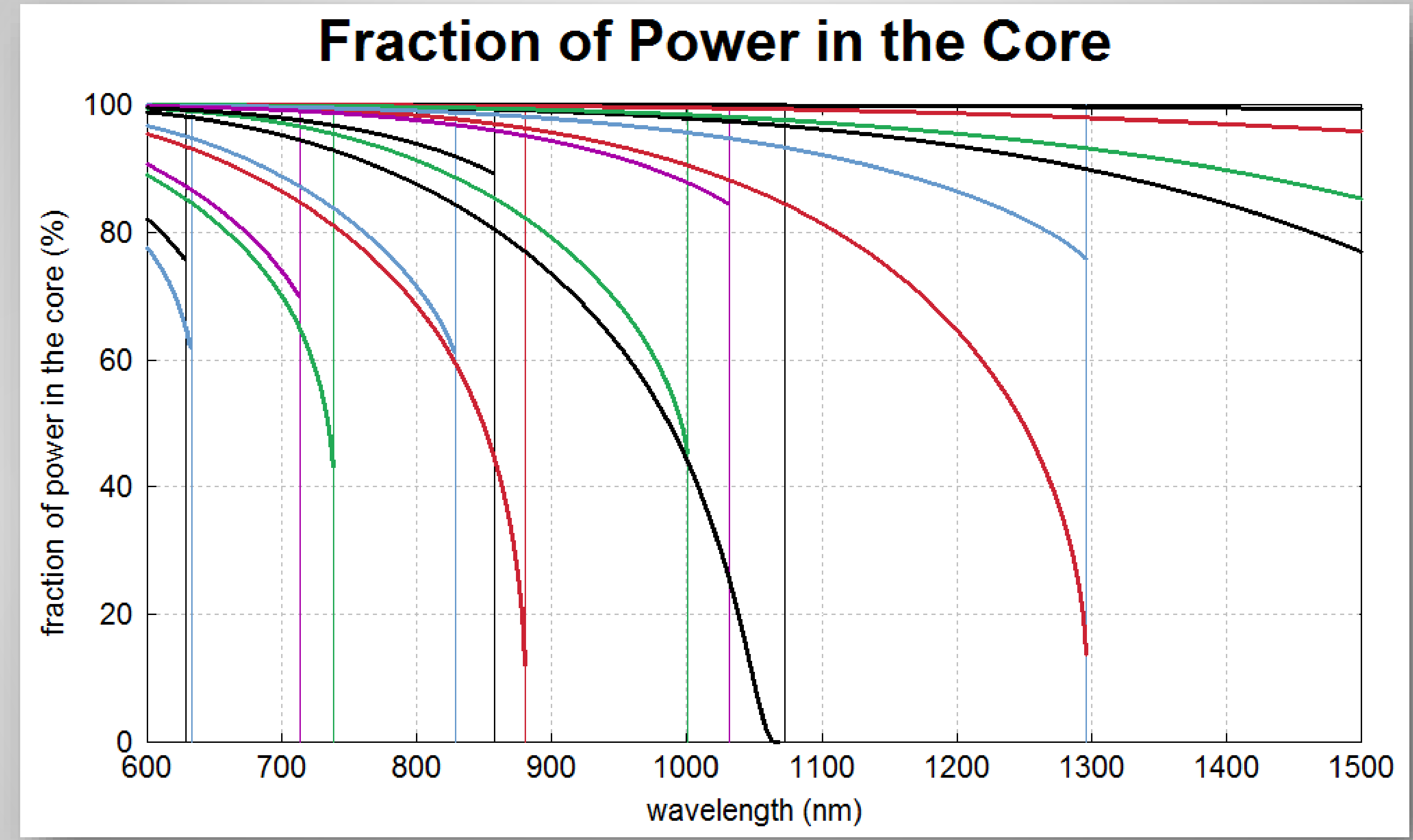
Calculation of Fiber Modes (2)



Calculation of Fiber Modes (3)



Calculation of Fiber Modes (4)



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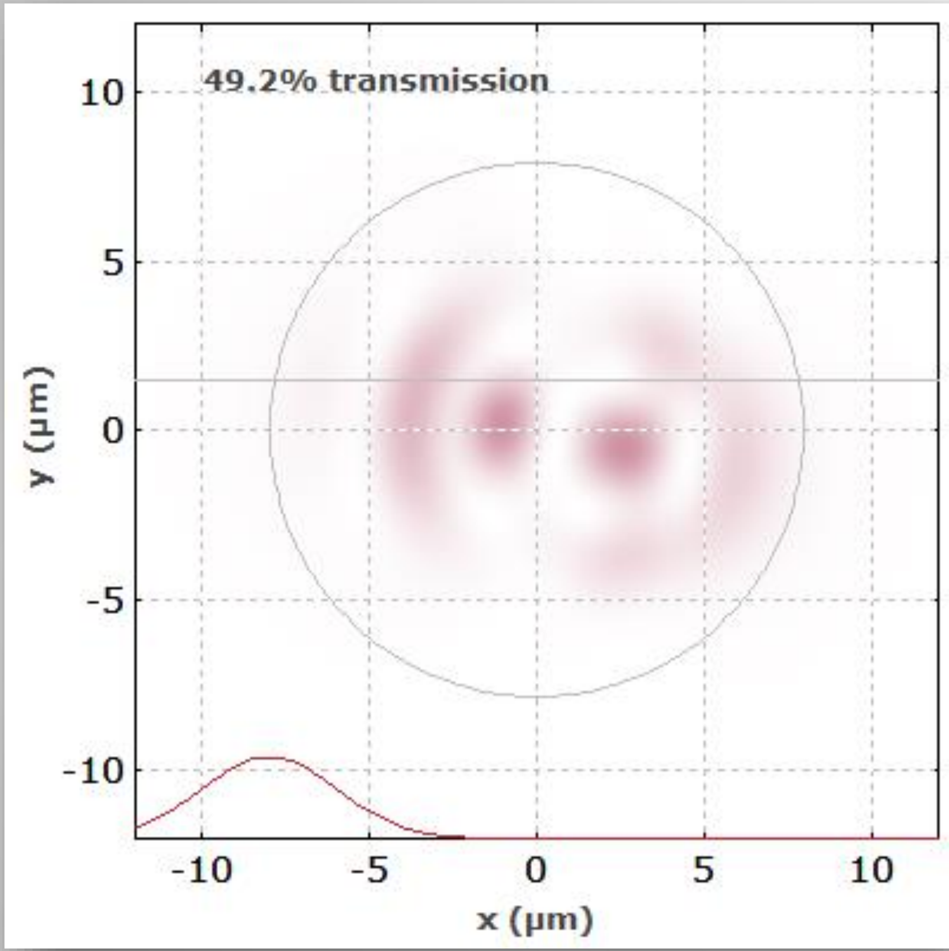
Calculation of Fiber Modes (5)

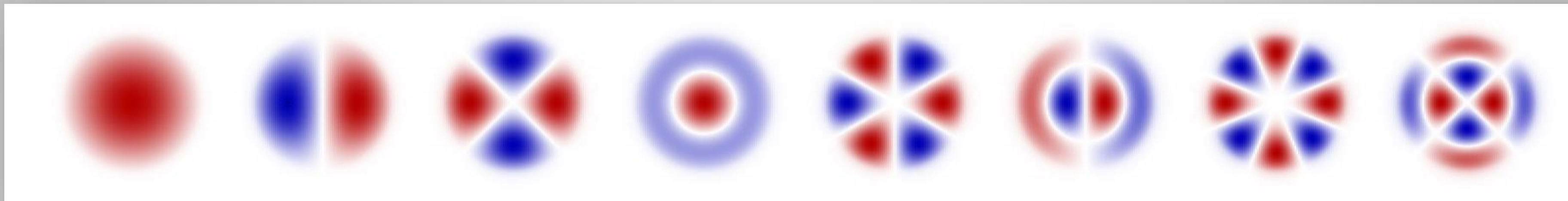
Example: Launching light into a multimode fiber



A simple script does the following:

- Fiber modes are calculated from the refractive index profile.
- Input light (here: misaligned laser beam) is decomposed into modes.
- Complex mode amplitudes change according to the different propagation constants.
- Resulting intensity profile at fiber end is displayed.

Calculation of Fiber Modes (6)

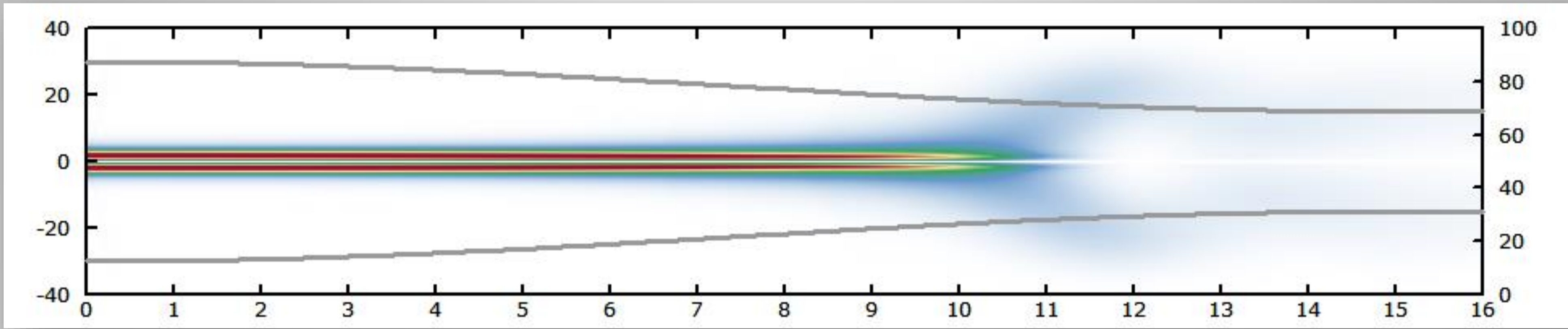


Applications:

- **Analyze** existing fibers in detail – fully understand their properties.
- **Optimize** fiber designs to obtain the needed modal properties.
- **Learn** a lot by playing with the model! For example, try out how mode properties react to changes of the index profile.

RP Fiber Power is a *must-have* if you work with fiber devices
and an *excellent educational tool* for fiber optics!

Numerical Beam Propagation (1)

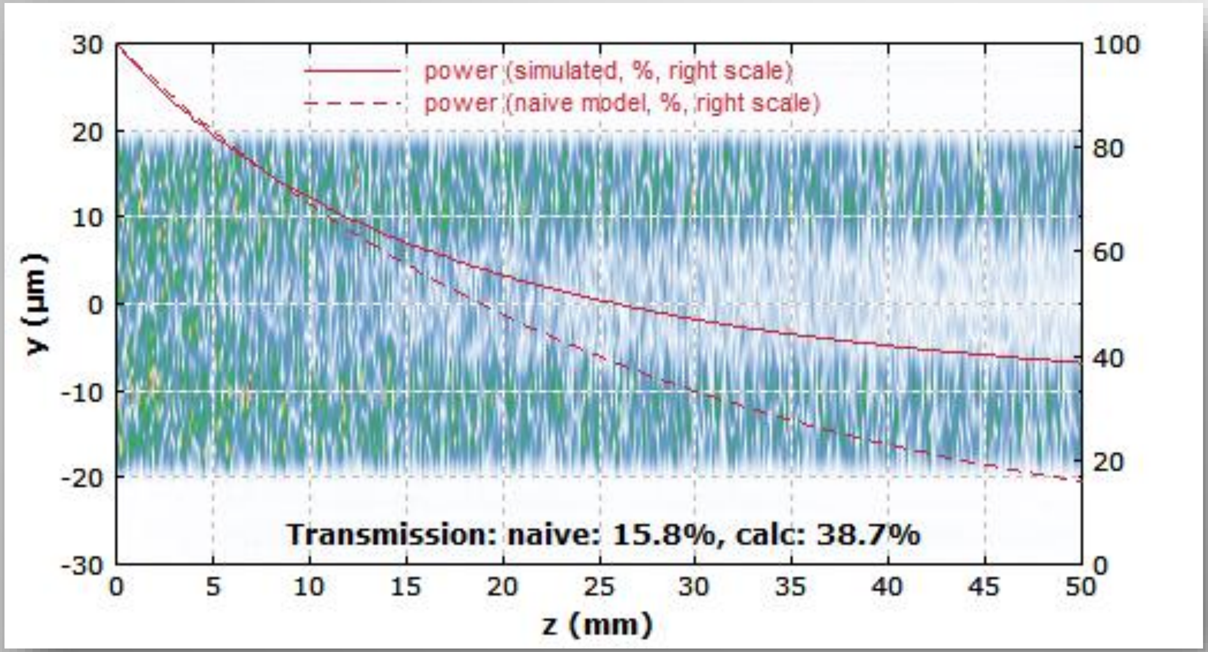


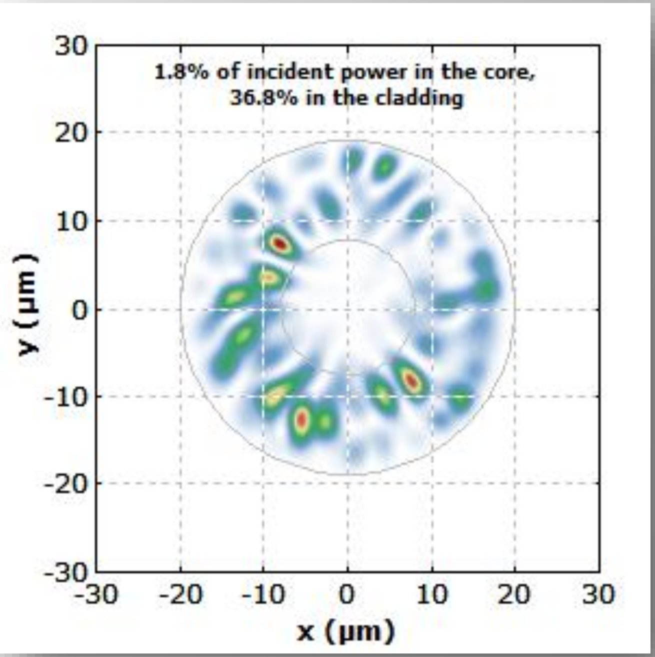
- Propagate arbitrary field distributions through fibers or other waveguides.
- Create structures as you like:
  may have tapered regions, variable bends, multiple cores, lossy regions, saturable laser gain, …
  → usable for double-clad fibers, fiber couplers, multi-core fibers, helical core fibers, etc.
- Optimize the designs even of very sophisticated devices.

Numerical Beam Propagation (2)

Example: pump absorption in a double-clad fiber

- Incomplete pump absorption due to helical cladding modes (see below).
- Can investigate how bending, an off-centered core, a D-shaped or octagonal cladding or other design modification improves the performance.

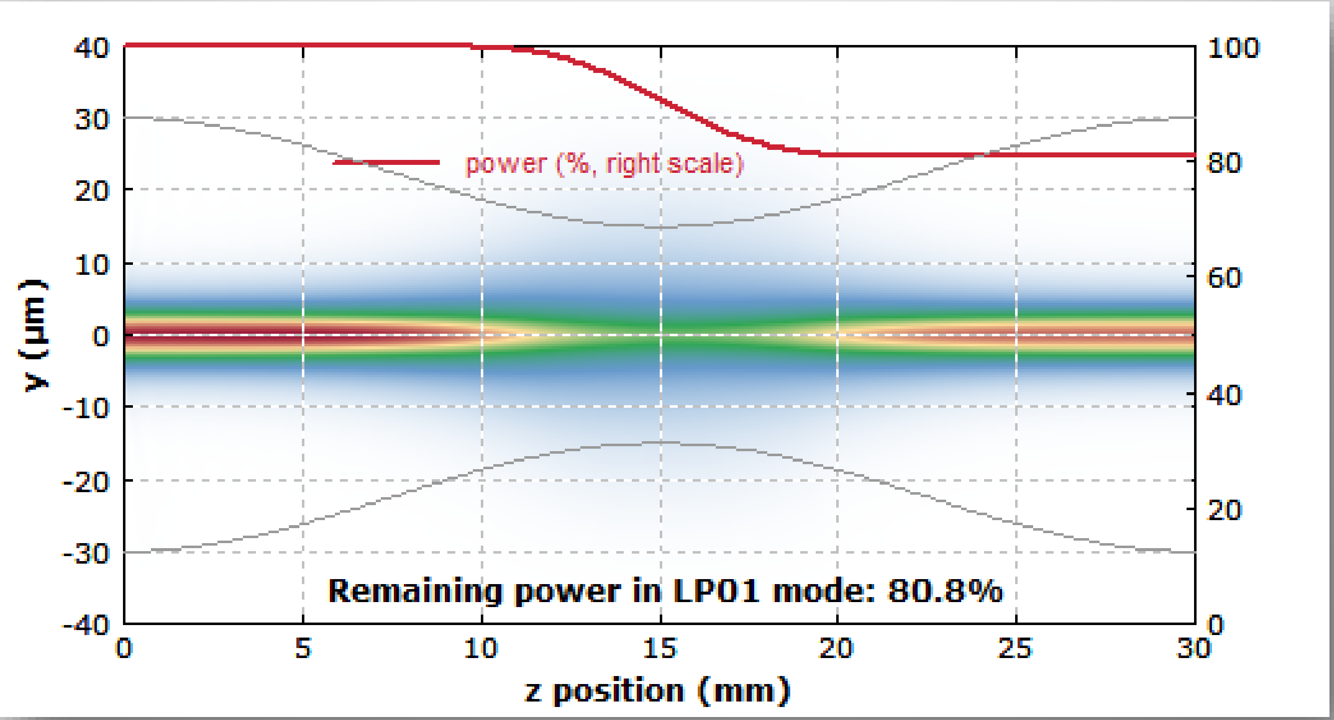




Numerical Beam Propagation (3)

Example: tapered fiber

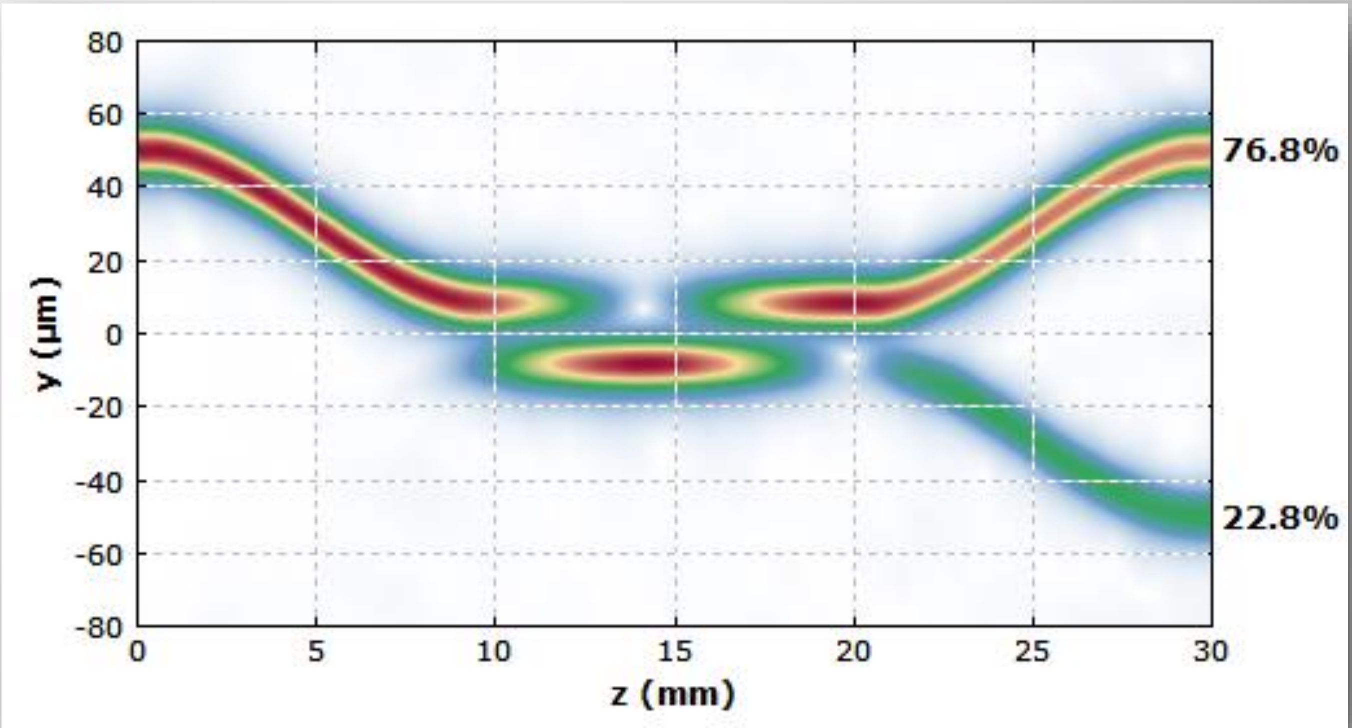
- Define a three-dimensional refractive index profile with a waveguide which gets narrower in some region.
- Study the wavelength- and mode-dependent losses.



Numerical Beam Propagation (4)

Example: fiber coupler

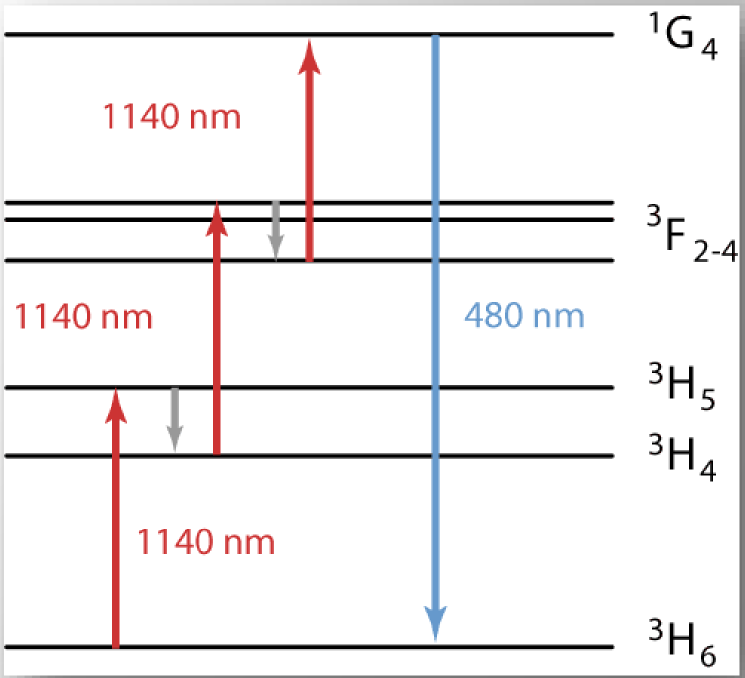
- Define a three-dimensional refractive index profile with two waveguides.
- Study evanescent field coupling. At long wavelengths, also get bend losses.



Calculation of Optical Powers (1)

Models for laser-active Ions:

- **Simple gain model:** only one metastable level, defined most easily. Applicable to Yb^{3+}, Nd^{3+}, and often for Er^{3+}, Tm^{3+}, etc.
- **Extended gain model:**
  - can have arbitrary user-defined level scheme
  - define arbitrary set of processes: spontaneous and stimulated emission, energy transfers and upconversion, …
  - Example case: Tm^{3+} upconversion laser.



Calculation of Optical Powers (2)

Define a **transverse density profile** of laser-active ions:

- Full transverse resolution: radial and azimuthal dependencies
- Multiple types of laser-active ions:
  for example, can have Yb^{3+} and Er^{3+} ions, with energy transfer between them. Each one can have its own density profile.
- Overlap with optical intensity profiles is calculated automatically.

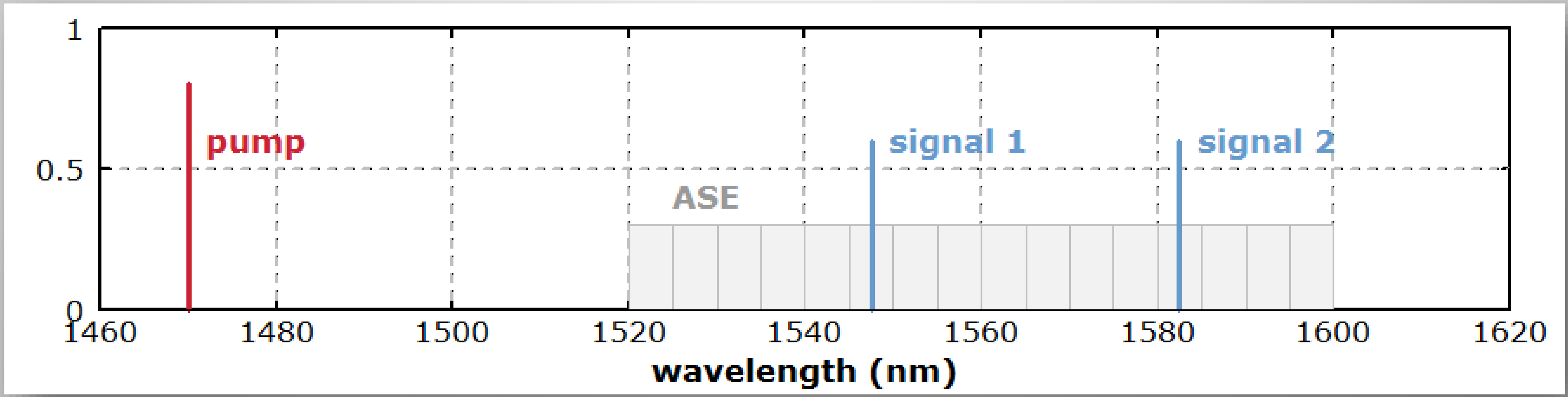
Calculation of Optical Powers (3)

Define **"optical channels"**:

- **Input channels**: for pump or signal waves, each with its own wavelength, power, propagation direction, intensity profile, …
- **ASE channels**: for amplified spontaneous emission

Can have hundreds of channels.

Intensity profiles can be taken from the mode solver, or specified otherwise.



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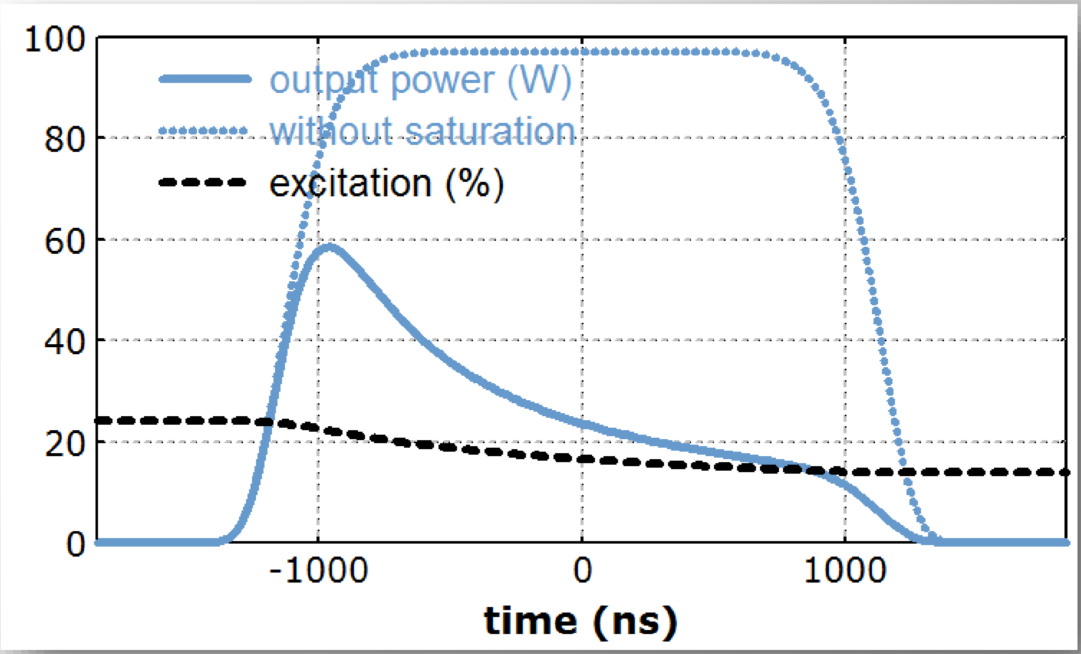
Calculation of Optical Powers (4)

Dynamical calculations:

- The input powers of all channels can have different time dependencies. Example: amplifier for short pulses with long pump pulses.
- Describe time dependencies with formulas. Functions are provided for accessing the calculated time-dependent output powers and excitation densities.

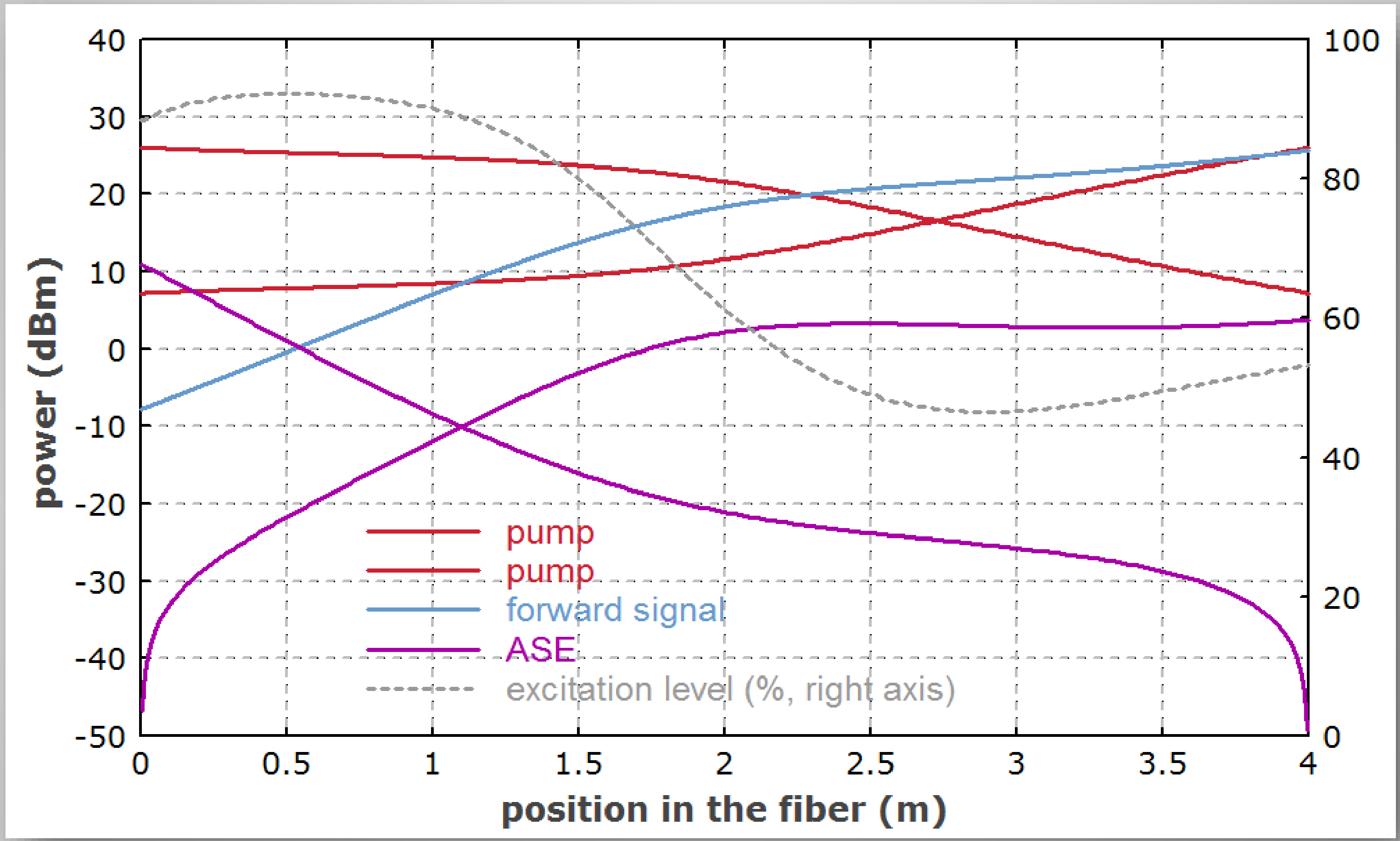
Applications:

- pulsed amplifiers
- Q-switched fiber lasers



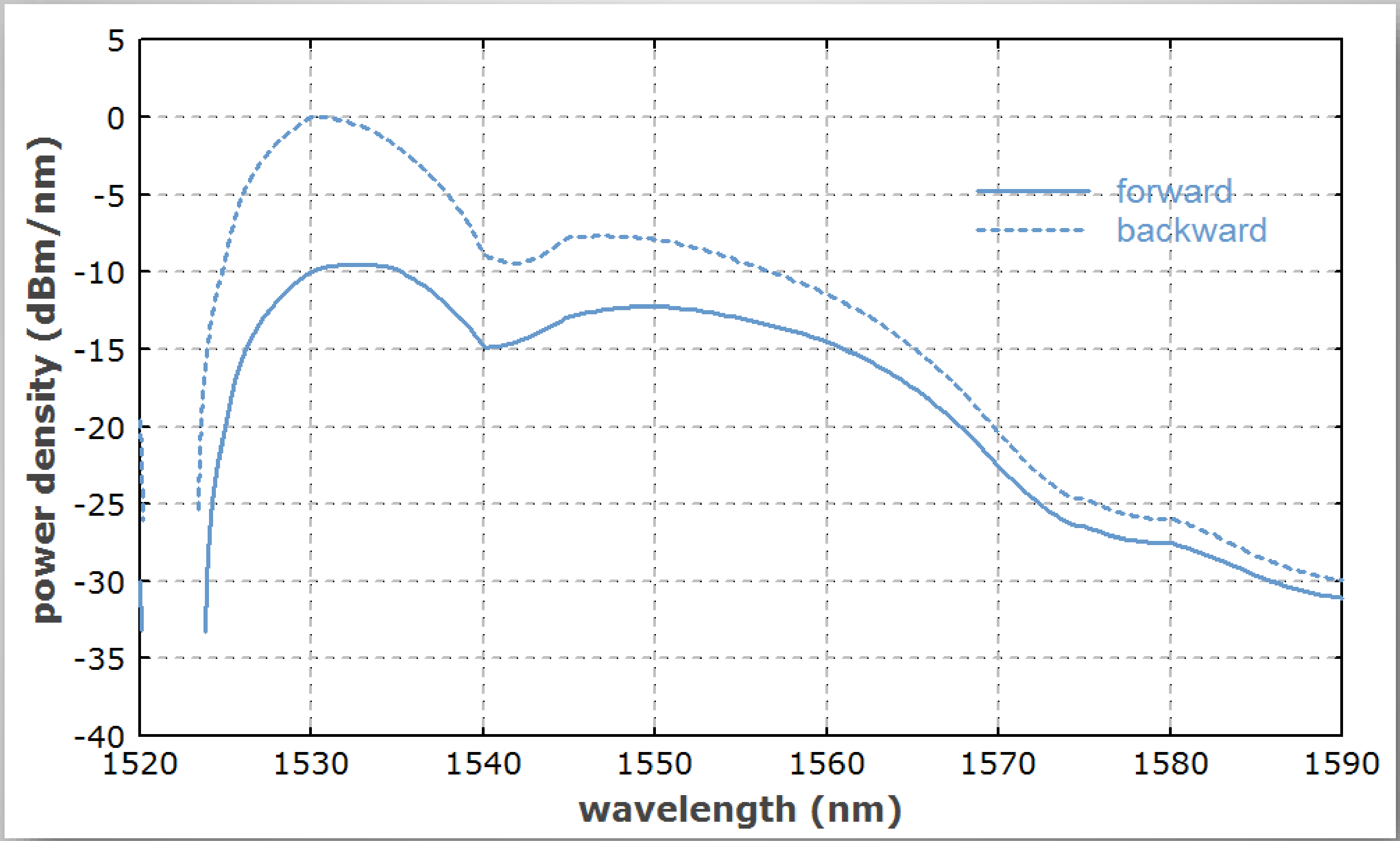
Calculation of Optical Powers (5)

Distribution of optical powers in an erbium-doped fiber amplifier



Calculation of Optical Powers (6)

ASE spectrum of an erbium-doped fiber amplifier



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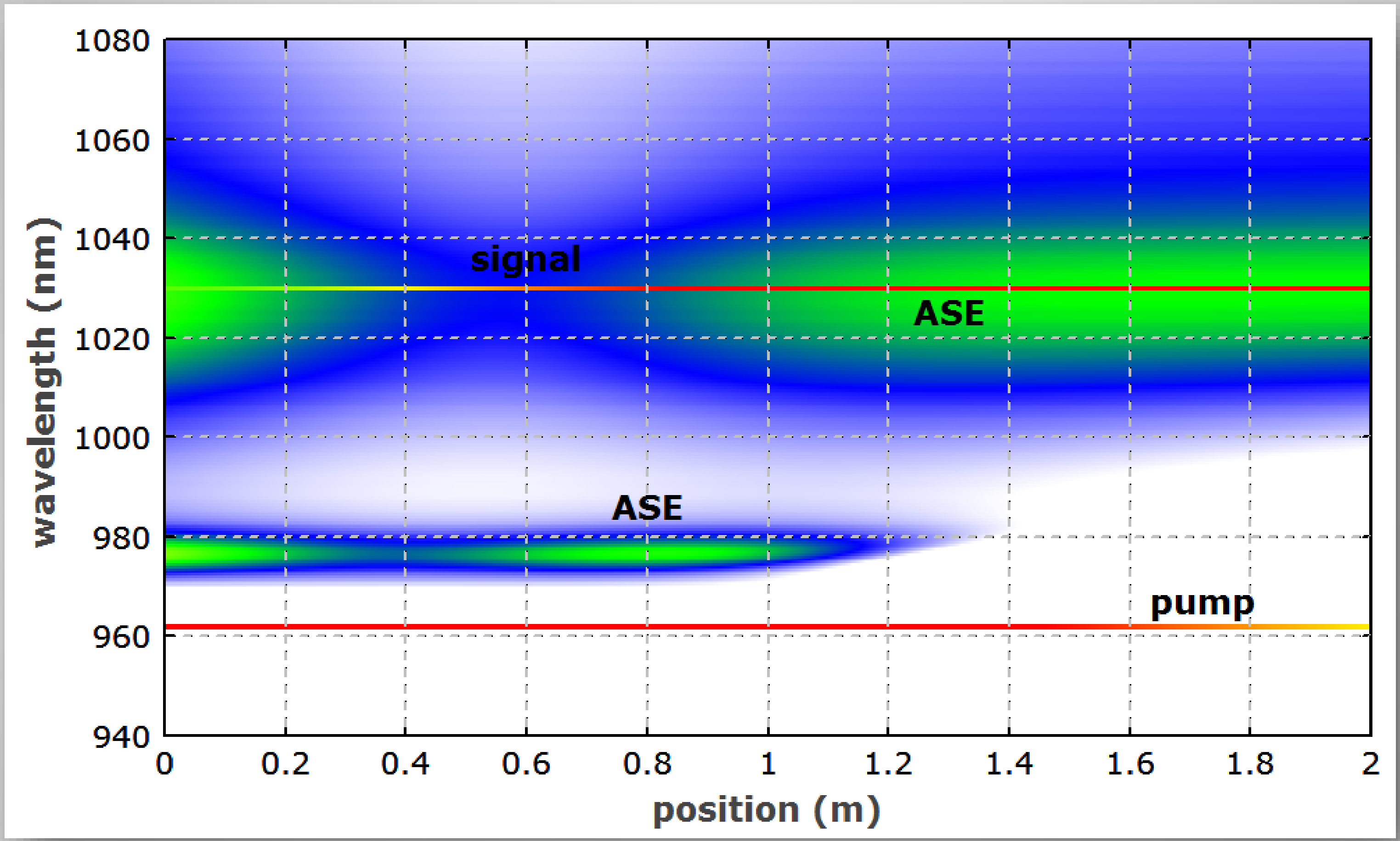
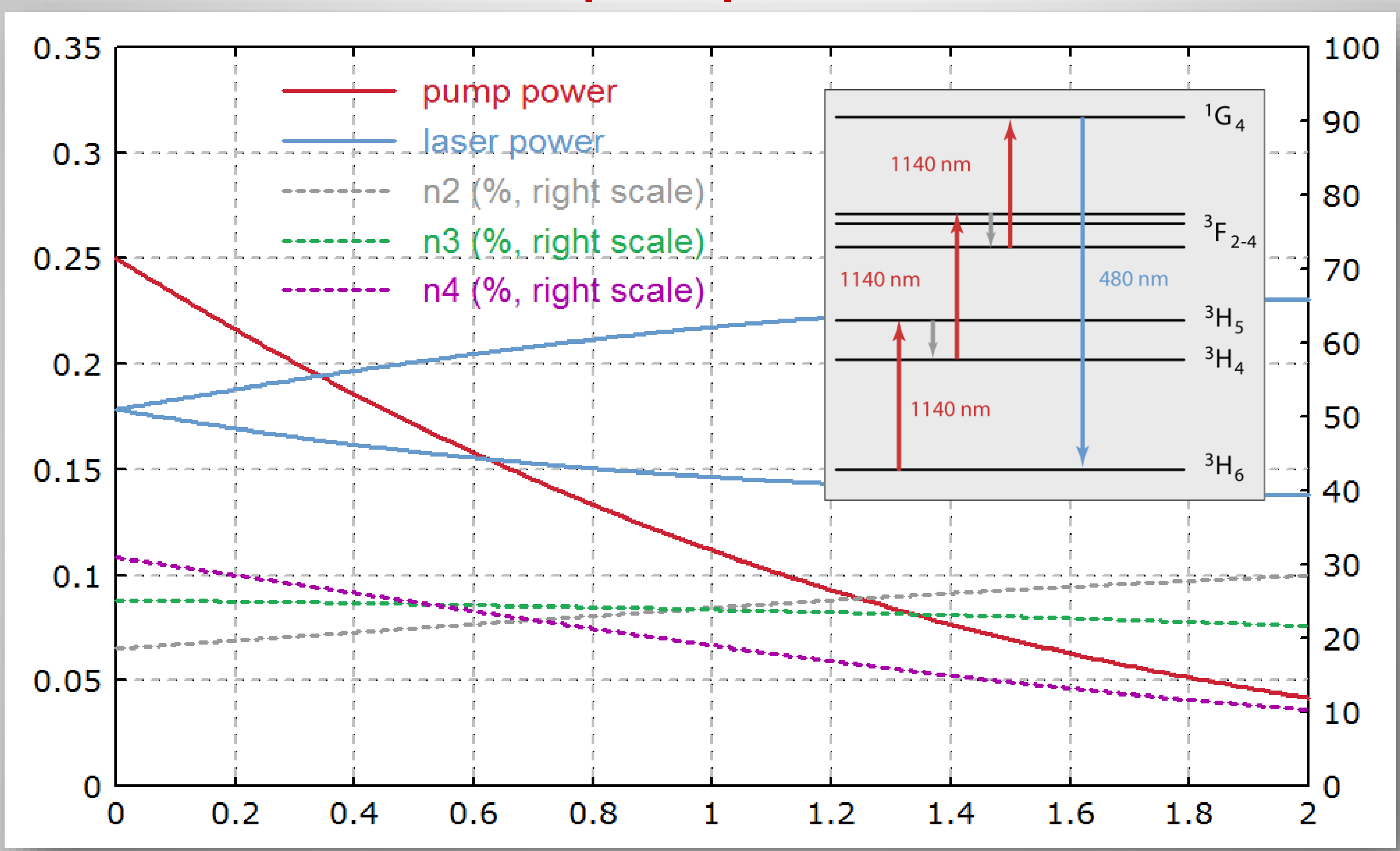
Calculation of Optical Powers (7)

ASE in ytterbium-doped amplifier



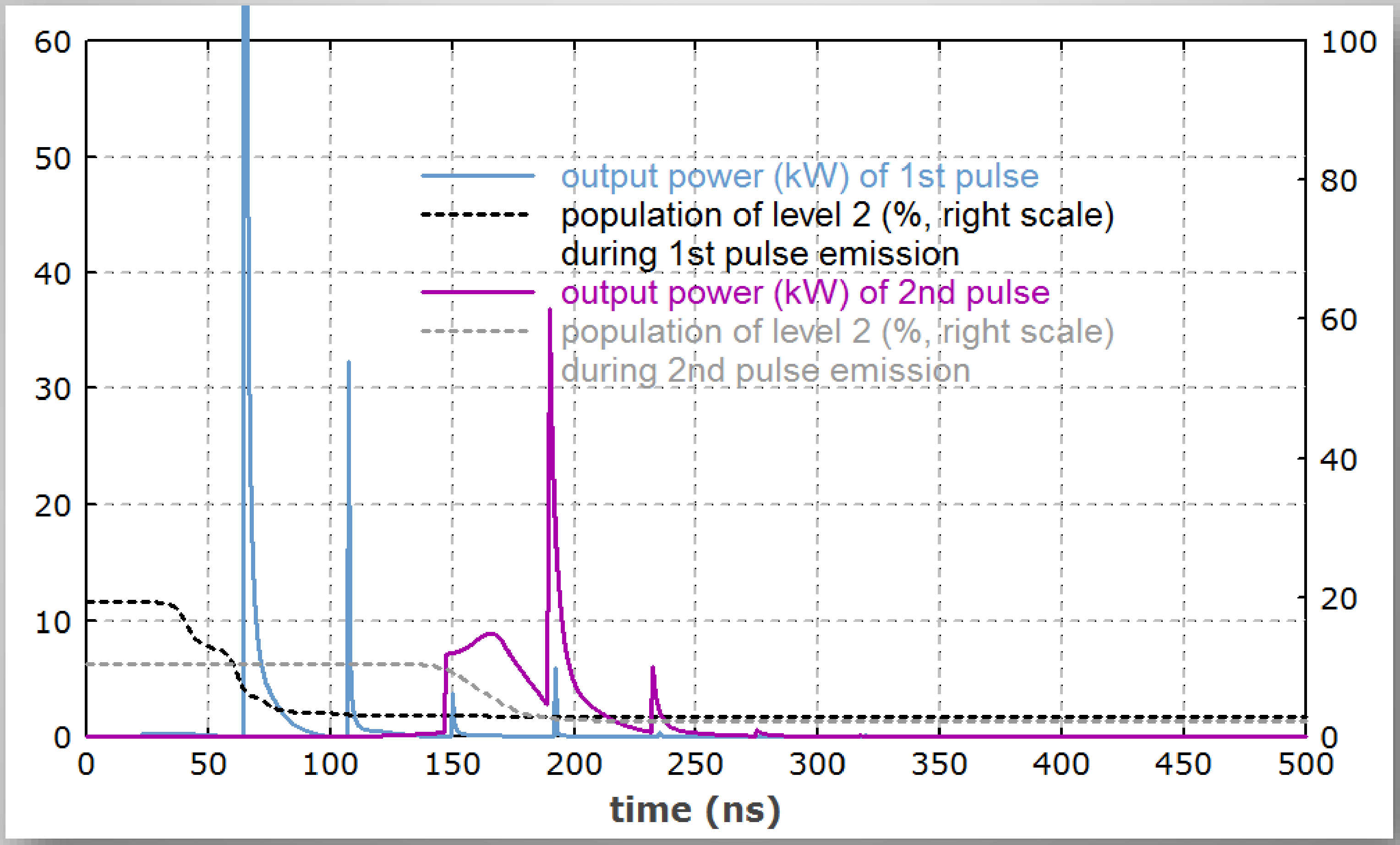
Calculation of Optical Powers (8)

Optical powers and excitation densities in a thulium-doped upconversion fiber laser



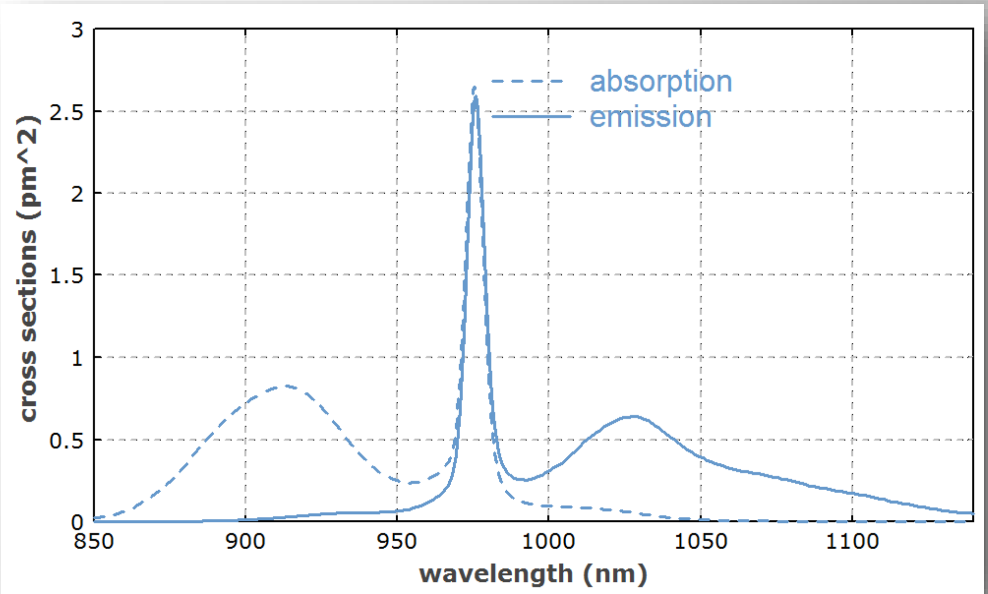
Calculation of Optical Powers (9)

Q-switched fiber laser



How to Get the Fiber Data

- **RP Fiber Power** comes with a variety of **data sets for various fibers**, including data of some commercial fibers from companies which teamed up with **RP Photonics** to facilitate calculations.
- If you have your own spectroscopic data, you can integrate them such that the software can use them in the same way as the originally provided data.
- If you first need to do spectroscopic measurements, you can obtain help from **RP Photonics** (this is support!), both concerning the measure-ments and the data processing.



Ultrashort Pulse Propagation (1)

- Take into account many **fiber properties**:
  - chromatic dispersion (may be calculated with the mode solver)
  - Kerr nonlinearity and stimulated Raman scattering, both also with self-steepening
  - wavelength-dependent amplification (based on fiber state calculated with a steady-state or dynamic simulation)
- Define a **start pulse**:
  - Gaussian pulse, sech^2-shaped pulse, or arbitrary pulse shape given in time or frequency domain
  - Can also take the pulse resulting from the last simulation, or a previously stored pulse

Ultrashort Pulse Propagation (2)

Additional features:

- spectral filtering before and after the fiber, or within the fiber

Obtain calculated pulse properties:

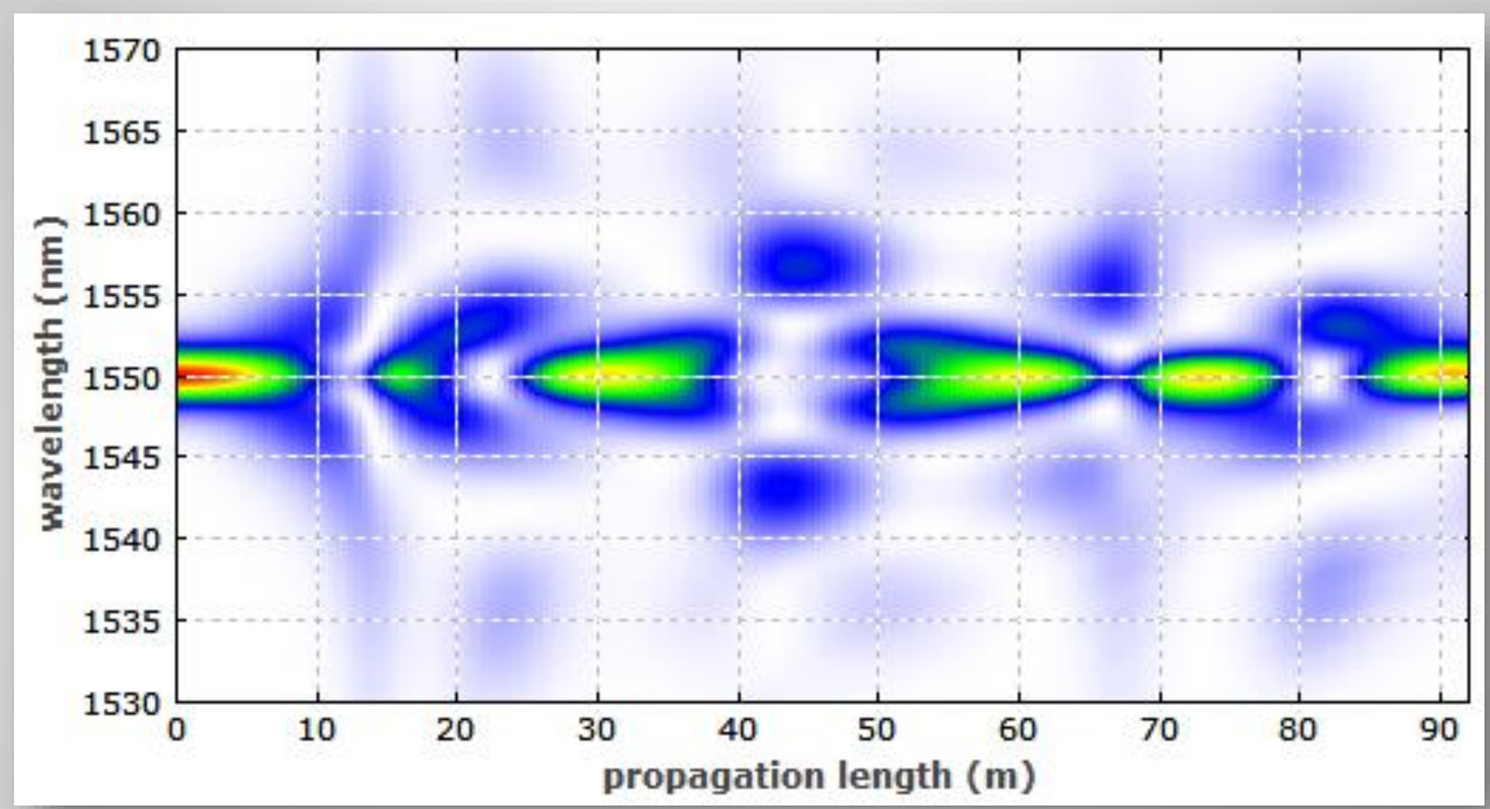
- Script language provides many dozens of **functions for retrieving all sorts of pulse properties**: pulse energy, peak power, peak position, pulse duration and spectral width (based on different definitions), amplitude profiles, spectral phase, autocorrelation, etc.
- Easy pulse inspection with the **interactive pulse display window**.

Control the simulation:

- Other functions can control the simulation – for example, do multiple passes through an amplifier, repeat simulation with different parameters, store pulses for later inspection, etc.

Ultrashort Pulse Propagation (3)

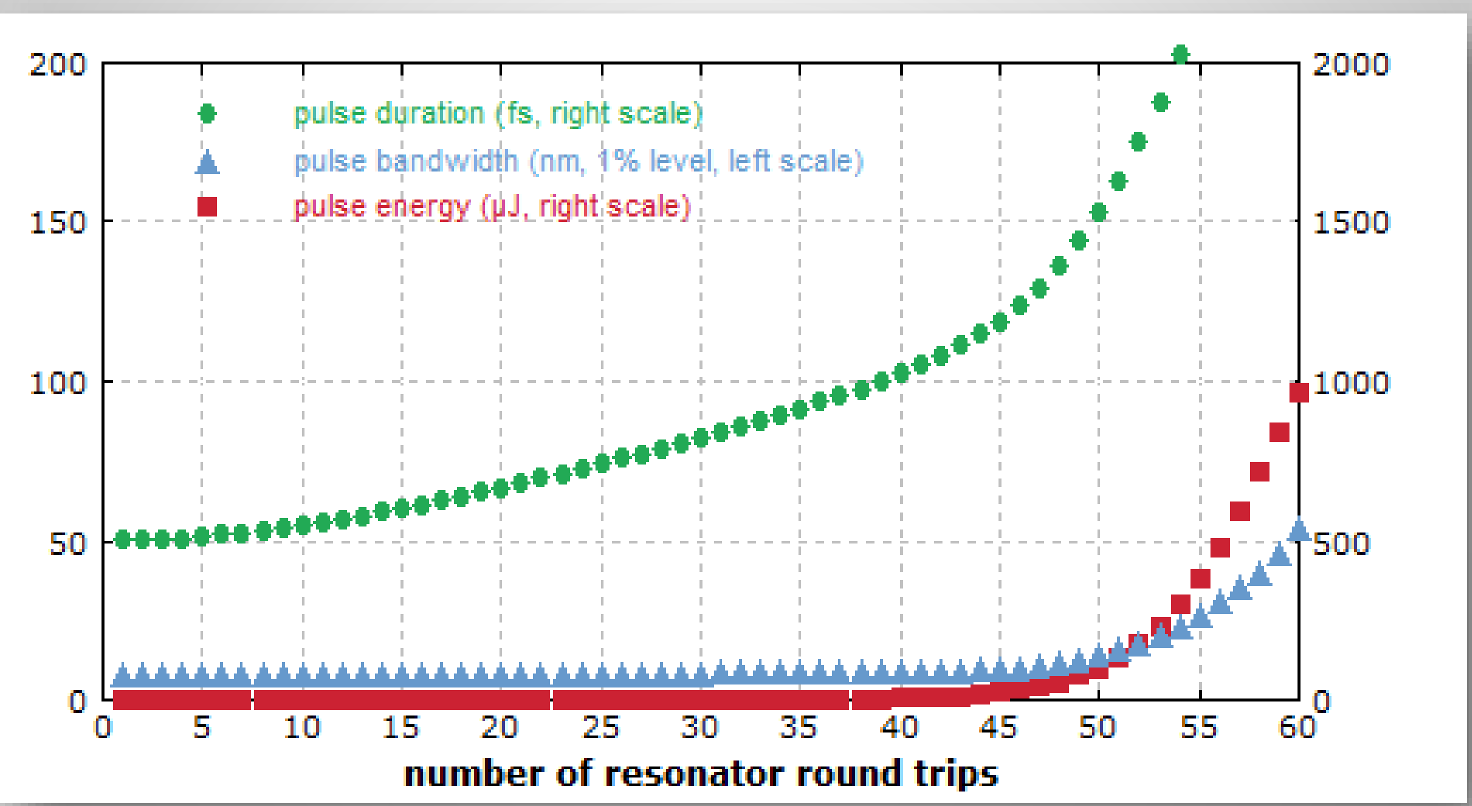
Example: higher-order soliton propagation:



(evolution is not perfectly periodic due to higher-order dispersion)

Ultrashort Pulse Propagation (4)

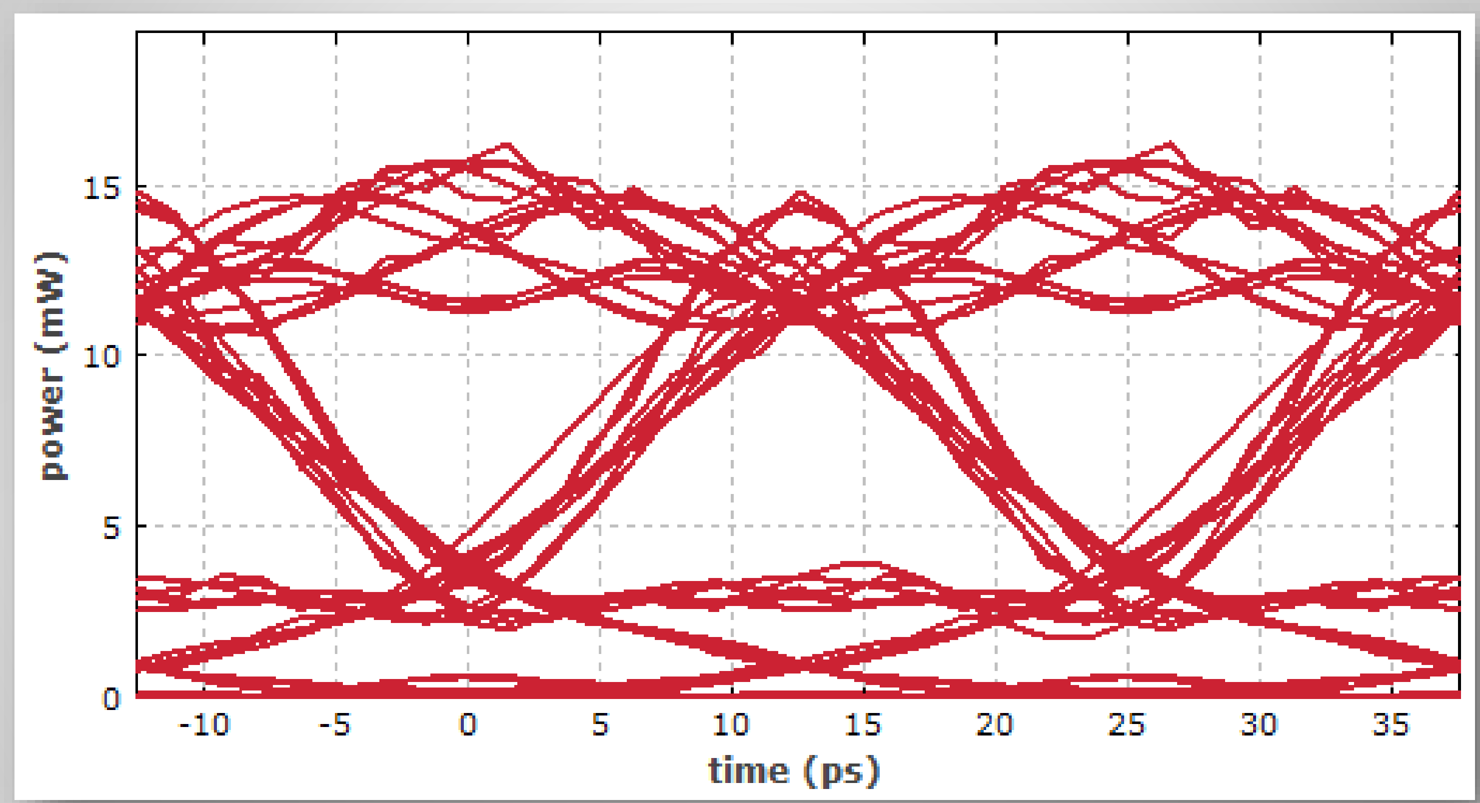
Example: regenerative bulk amplifier:



(Can easily simulate multiple amplification and pumping cycles, get steady-state values, etc.)

Ultrashort Pulse Propagation (5)

Example: optical data transmission in telecom fiber:



(Eye diagram generated with pseudorandom bit sequence.)

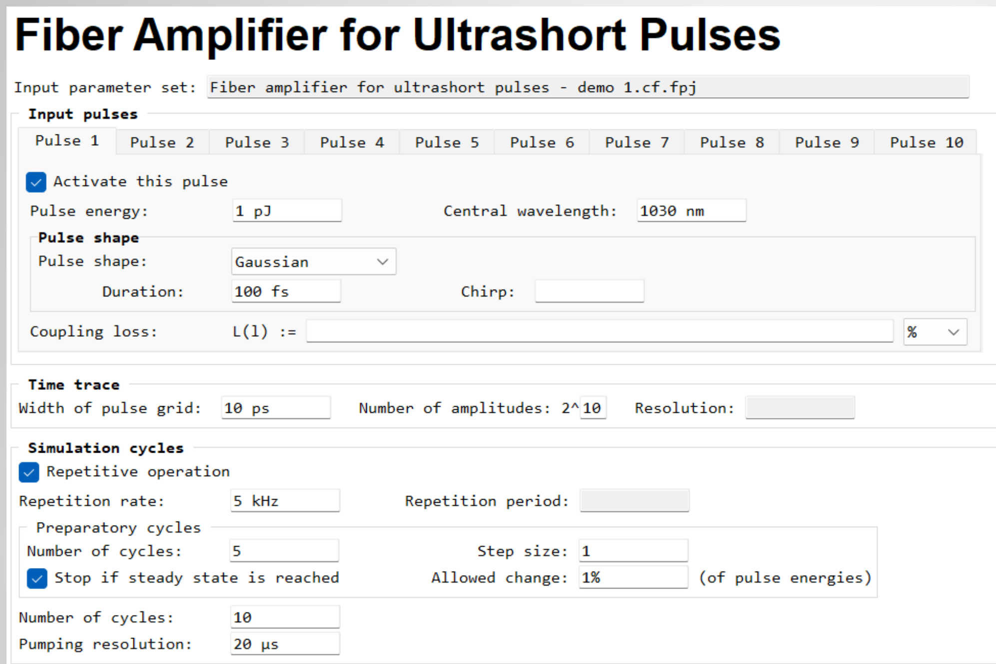
The User Interface (1)

New in RP Fiber Power V8: Power Forms!

- The software comes with several such forms, offering easy-to-use and very powerful simulation models for things like
  - fiber amplifiers for multiple continuous-wave (possibly broadband) signals, or with multiple short or ultrashort pulse signals
  - offering up to 5 fiber amplifier stages, with wavelength-dependent losses between them
  - flexible pumping options, including multiple bidirectional broadband pumps
- Just fill in your input parameters, select and configure the wanted diagrams, and execute!
- Get numerical outputs in the form as well as informative and nice diagrams.

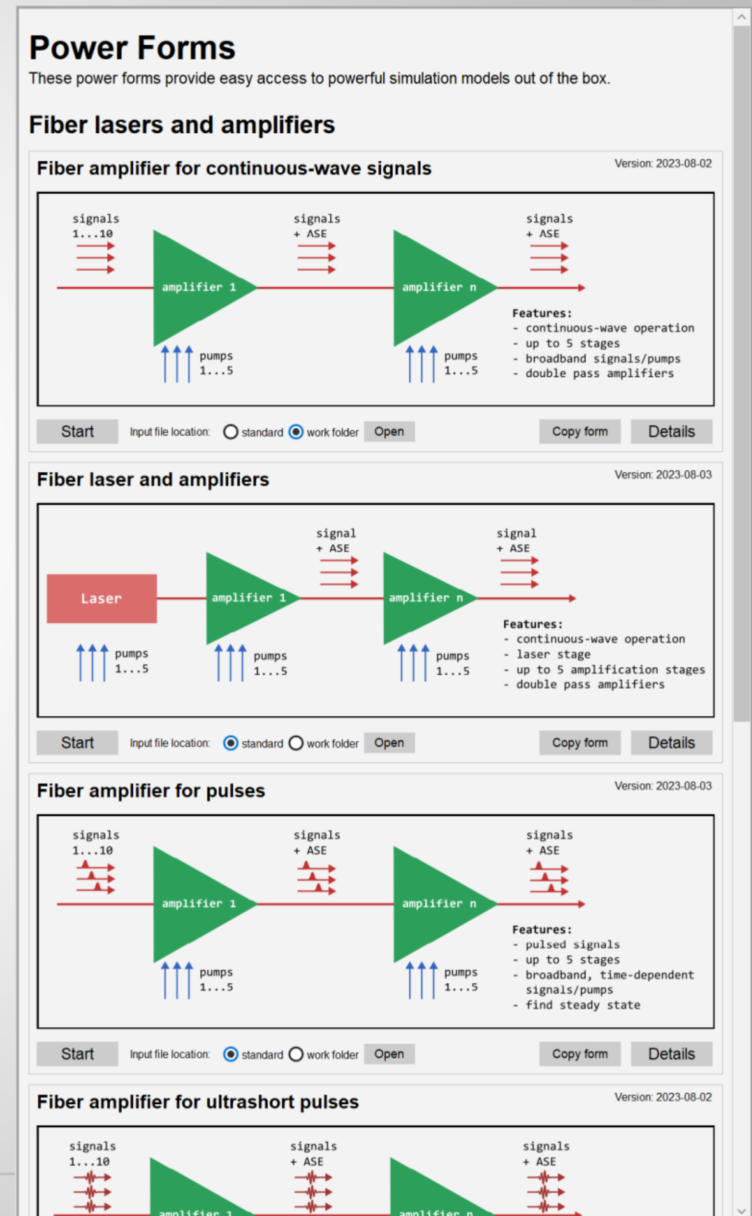
The User Interface (2)

- Simply pick the suitable Power Form. Example:



(This is only the beginning of the form; there is more, e.g. for defining details of the amplifier stages and for configuring diagrams.)

- The input data may be stored either in some standard folder or in your work folder.



The User Interface (3)

Combining power, flexibility and easy of use with Power Forms

- You can very easily set up simple fiber laser or amplifier models, for example, but can also utilize many sophisticated features, such as multiple stages, multiple broadband pumps and signals, wavelength filtering, many diagrams, etc.
- In case that some needed special feature is still missing: just add it! How does that work?
  - Power Forms are not "hard-wired" in the software, but rather defined in script files.
  - For making a modified version, let the software copy the script file to your work folder and edit it there – for example, adding a diagram, some input and output fields, etc.
  - If you meet any obstacles, contact our technical support. We can quickly provide modified Power Form versions for you.
- In that way, we managed to **combine ease of use with great flexibility**.

The User Interface (4)

Custom forms: make any tailored forms you need!

- Before we introduced the Power Forms, we had **Custom Forms**. In fact, Power Forms are basically sophisticated Custom Forms which we deliver with the software.
- Basic idea: a Custom Form contains
  - (a) code to define a form (defining input and output fields, buttons, tab controls, radio boxes etc.
  - (b)code for calculations and generating outputs (numerical or diagrams)
- You can make such forms yourself (with our support) for any new application of the software!

```
Custom form:
-----------------------------------------------------------------
$font: "Arial", bold, size = 20
Step-index Fiber
$image ((var r; r := if abs(y - 30 / 2) < 4 then 0.8 else 0.9; rgb(
$font: "Courier New", size = 11, space = 2.1
$box "Fiber details", size = (600, 0)
Core diameter:      ############   Clad index: ############
$input d_co:d6:"m", min = 0, max = 1e-3
$input n_cl:d6, min = 1, max = 2
Numerical aperture: ############   Core index: ############
$input NA:d6, min = 0, max = 1
$output n_co:f6
Super-Gauss index:  ############ (0 = step index)
$input sg_index, min = 0, max = 1000, default = 0, hint = "use a va
$box end
$box "Fiber modes", size = (600, 0)
Wavelength:         ############
$input lambda:d6:"(n)m"
```

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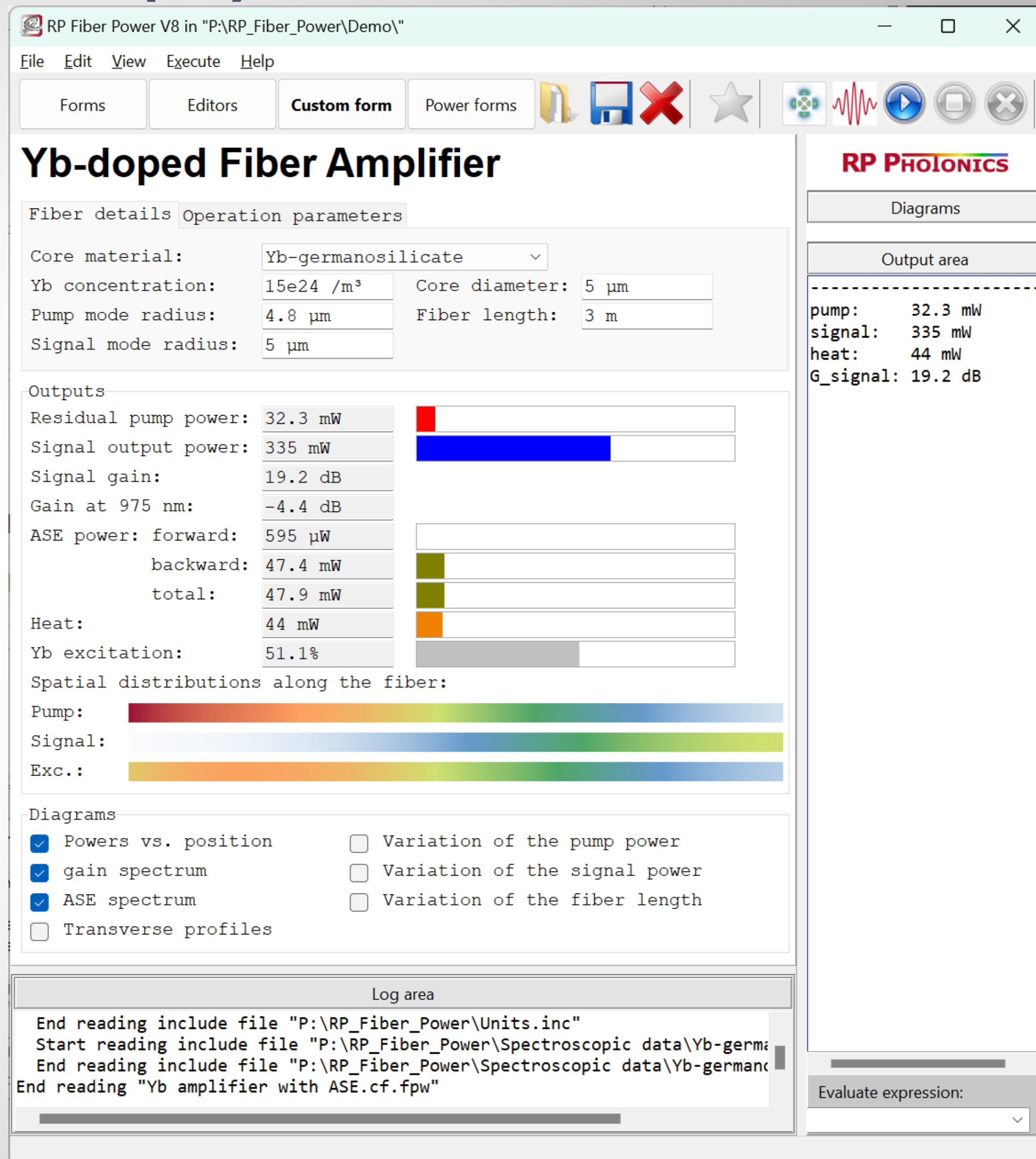
The User Interface (5)

Simple example for a **custom form:**

fiber amplifier model, calculating the spatial distribution of powers, output powers etc., also generating various plots

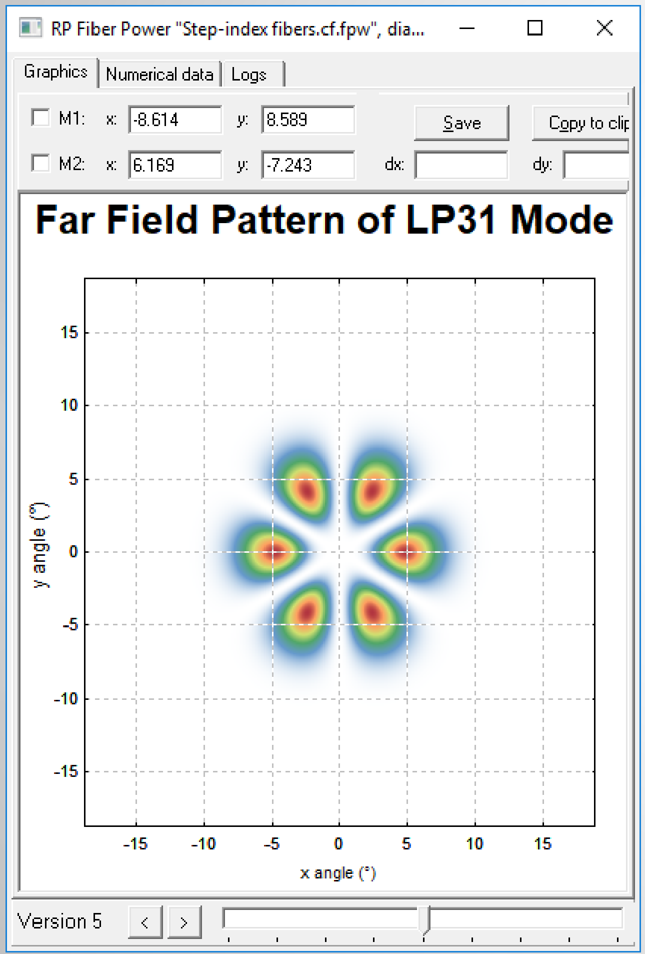
This is a delivered demo file. No problem if you need e.g. three signals instead of one – just modify the script!

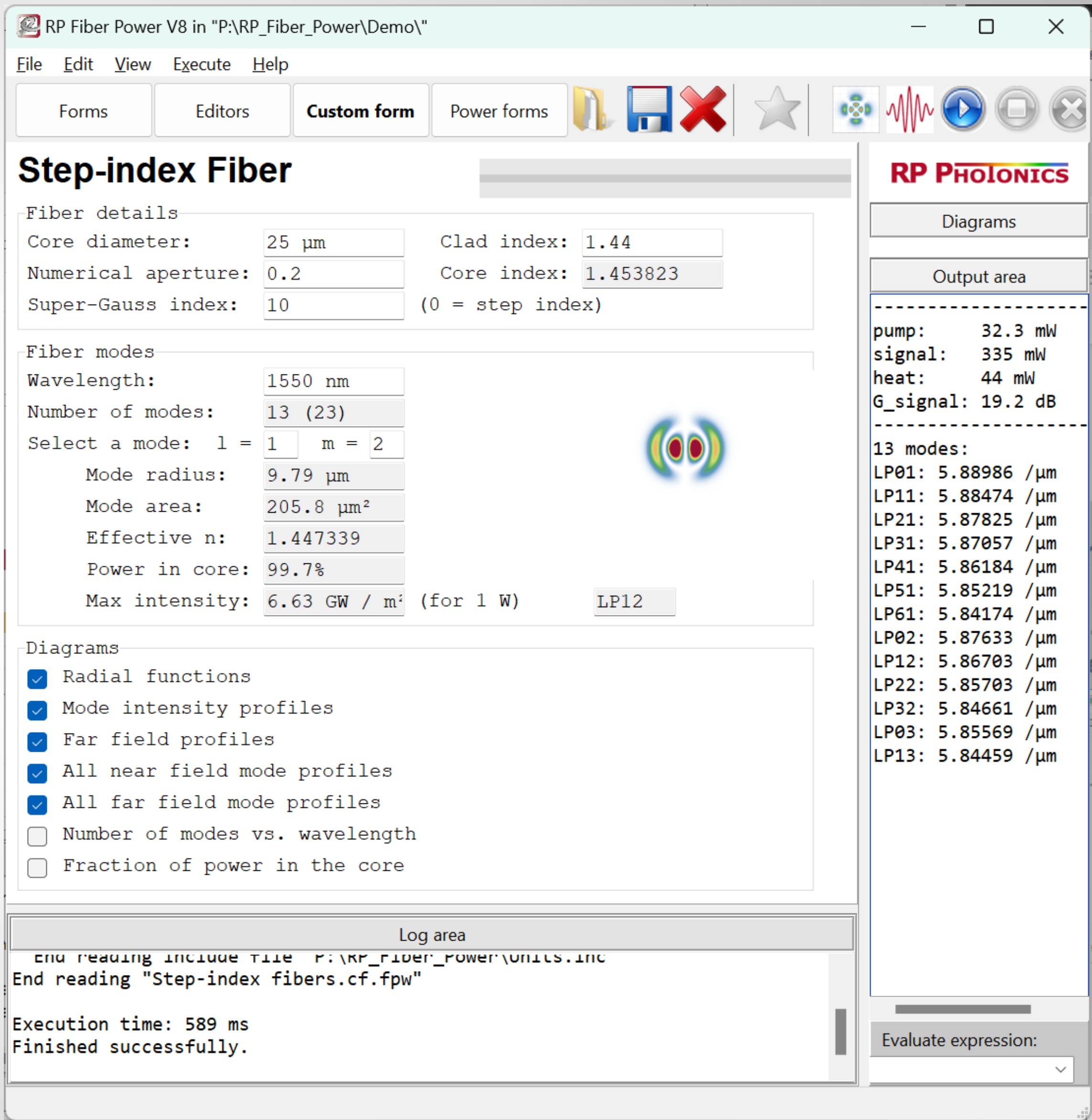
But for that specific use, an existing Power Form is far more powerful.



The User Interface (6)

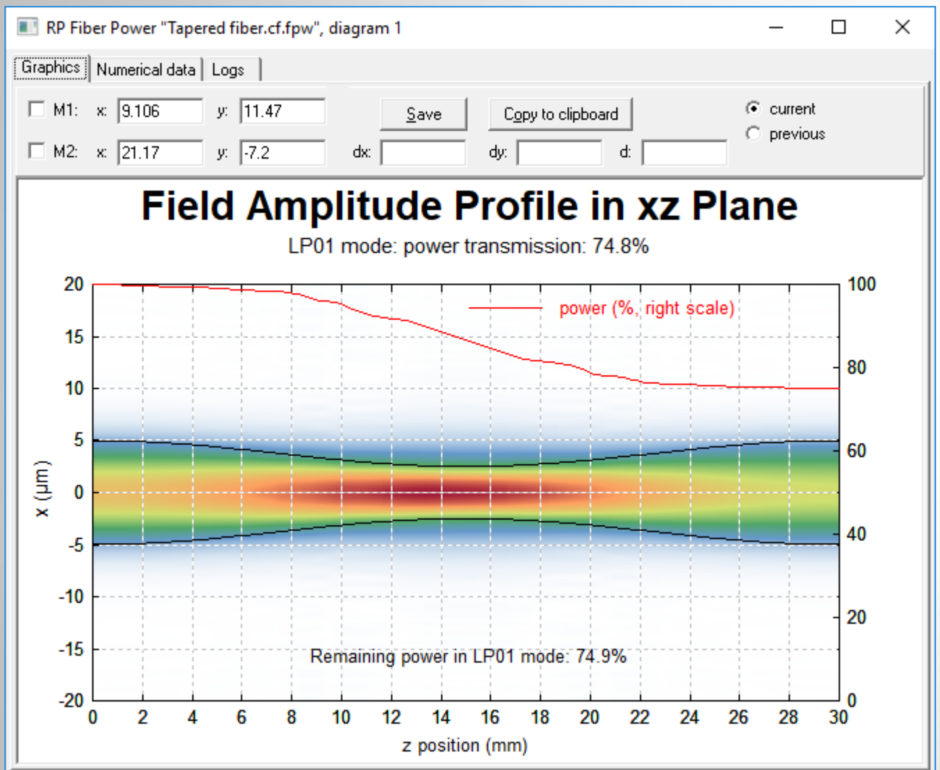
Another example: step-index fibers

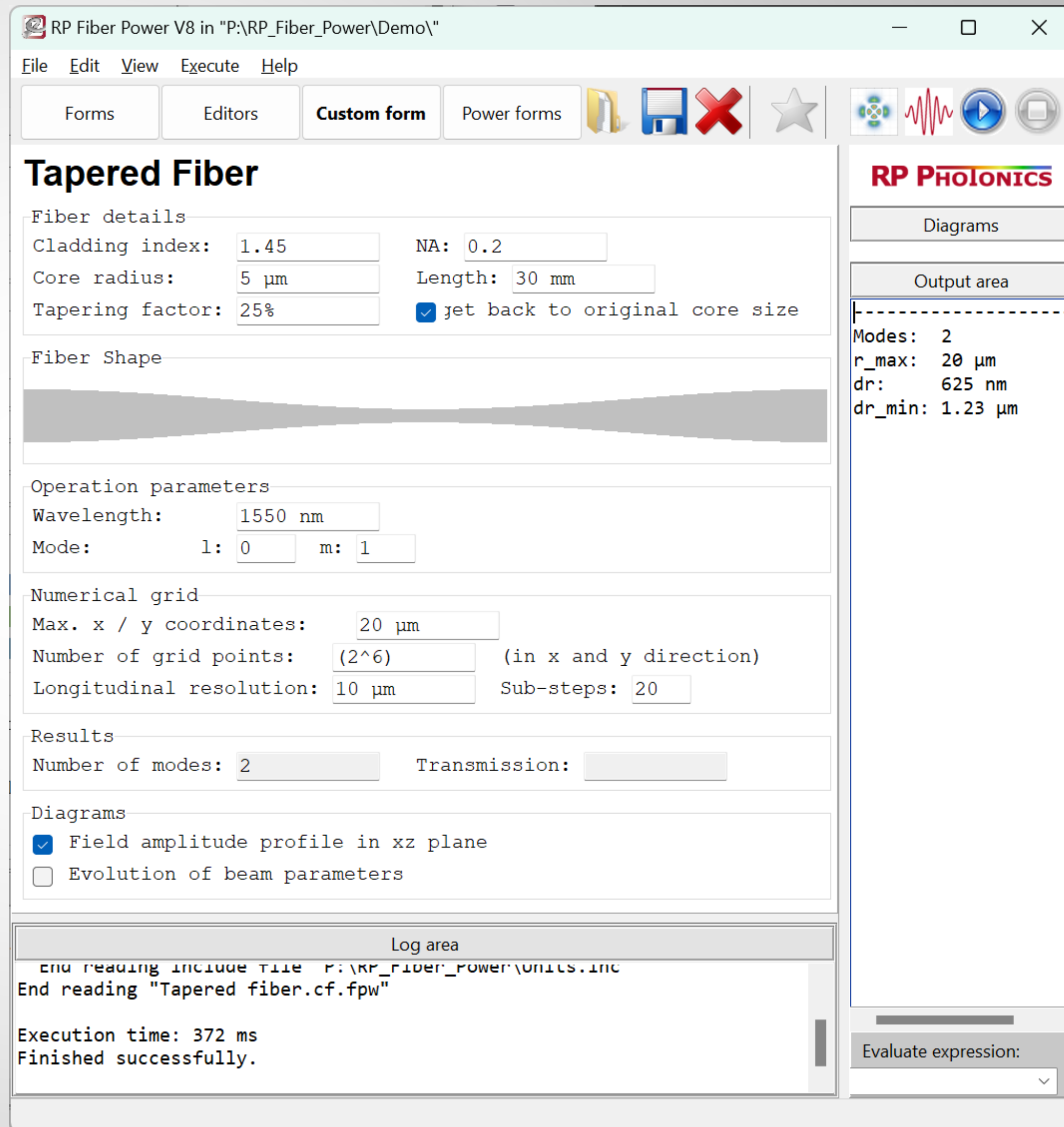




The User Interface (7)

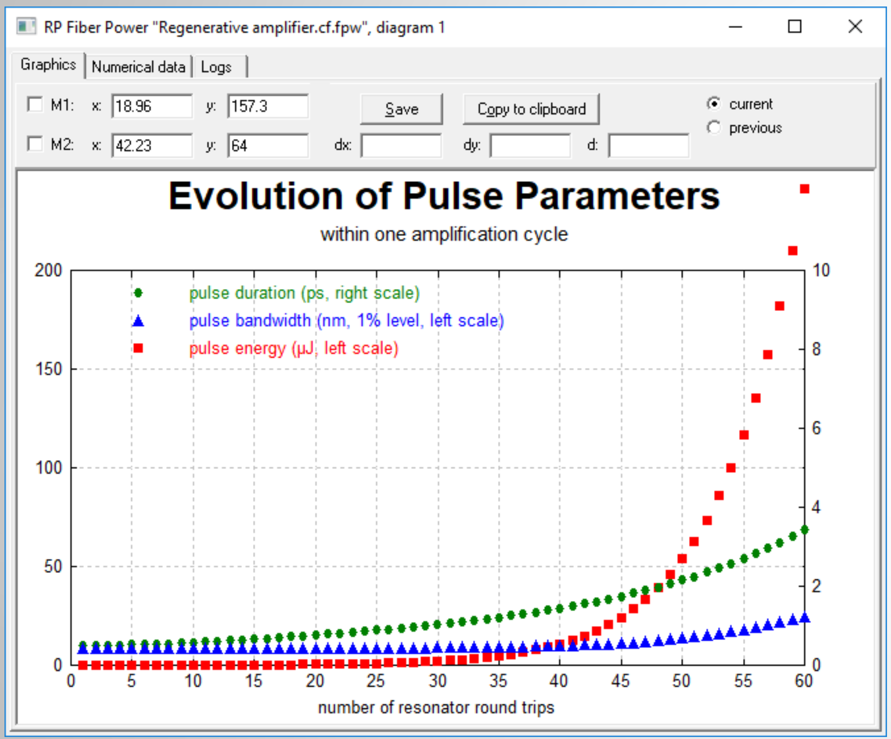
Another example: simulating light propagation in tapered fibers

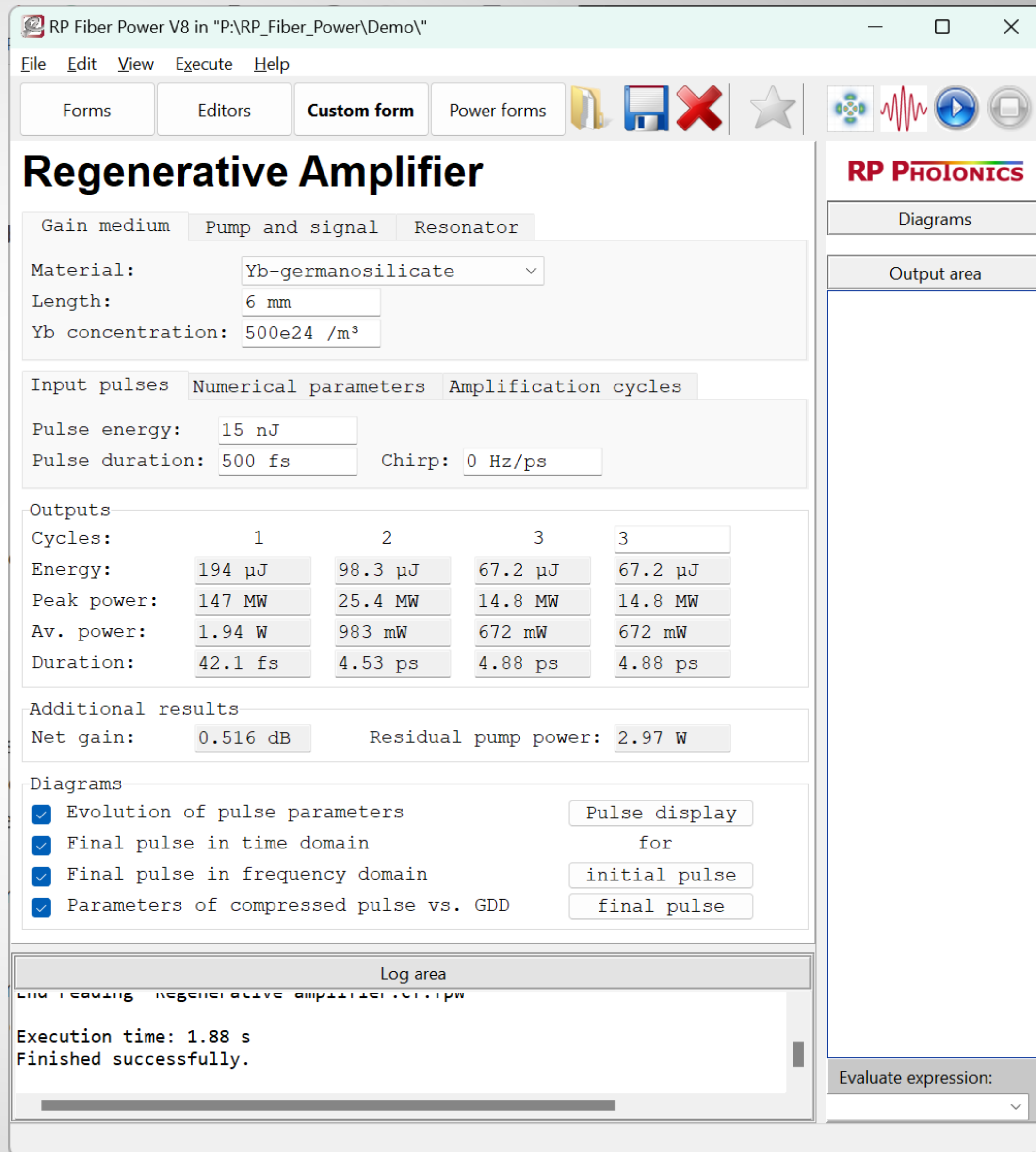




The User Interface (8)

Another example: regenerative amplifier





The User Interface (9)

In a script, you can define the following:

- any model (e.g. a sophisticated multi-stage fiber amplifier model)
- any further calculations
- generation of multiple graphical diagrams
- output or input to/from text or binary files
- a custom form for easy handling

```
DoCycle(N_rt, T_p) :=
  { Do one amplification phase with N_rt round trips
    and one pumping phase with duration T_p. }
  begin
    global E0, tau0, chirp0, N_rt, T_p;
    startpulse_G(E0, tau0, chirp0);
    { Amplification }
    for j := 0 to N_rt do
    begin
      if j > 0 then
      begin
        DoRoundTrip();
        describe_pulse("pulse after " + str(j) + " round trips");
      end;
      store_pulse(j);
    end;
    { Pumping }
    calc_dyn(0, T_p, minr(100 us, T_p));
  end
```

The User Interface (10)

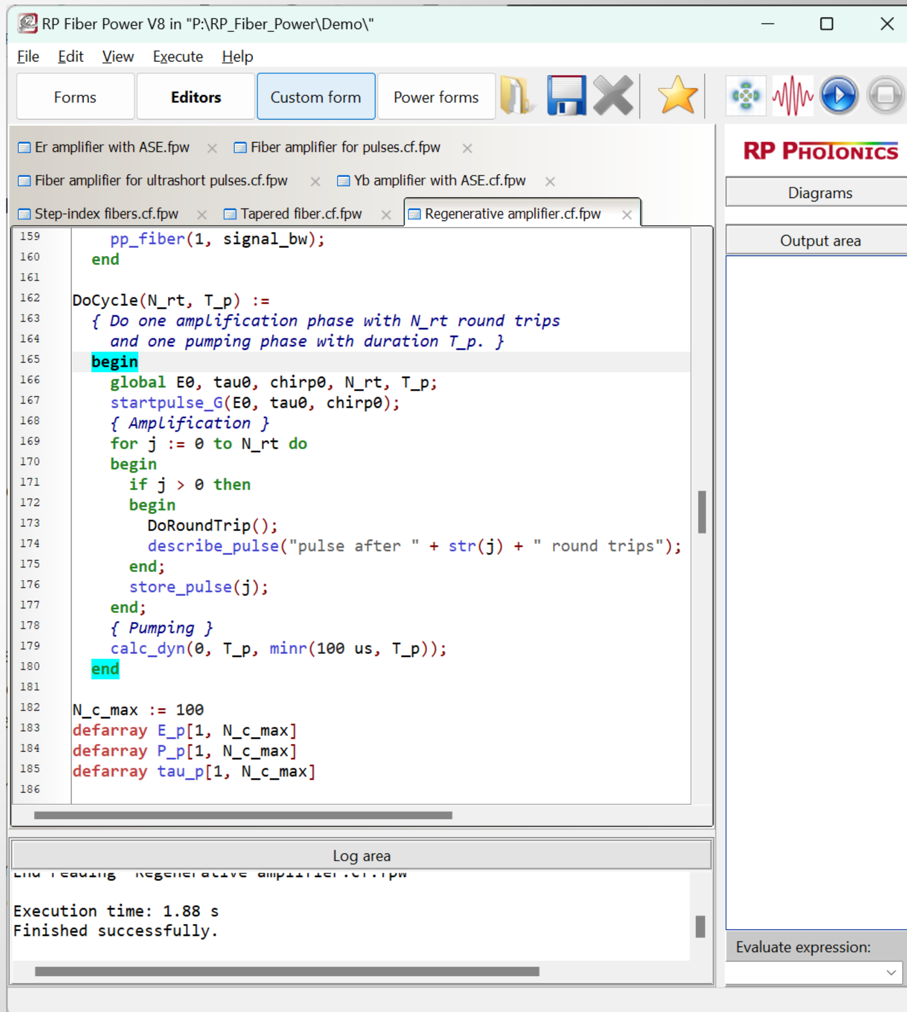
Where to get a script from?

- Take one of the many demo scripts coming with the software and adapt it to your specific needs.
  The user interface will support you in many ways.
- For a sophisticated model, may also start from a Power Form.
- Get help within the technical support – get even complete scripts developed for you!

The User Interface (11)

Powerful script editors and editing tools:

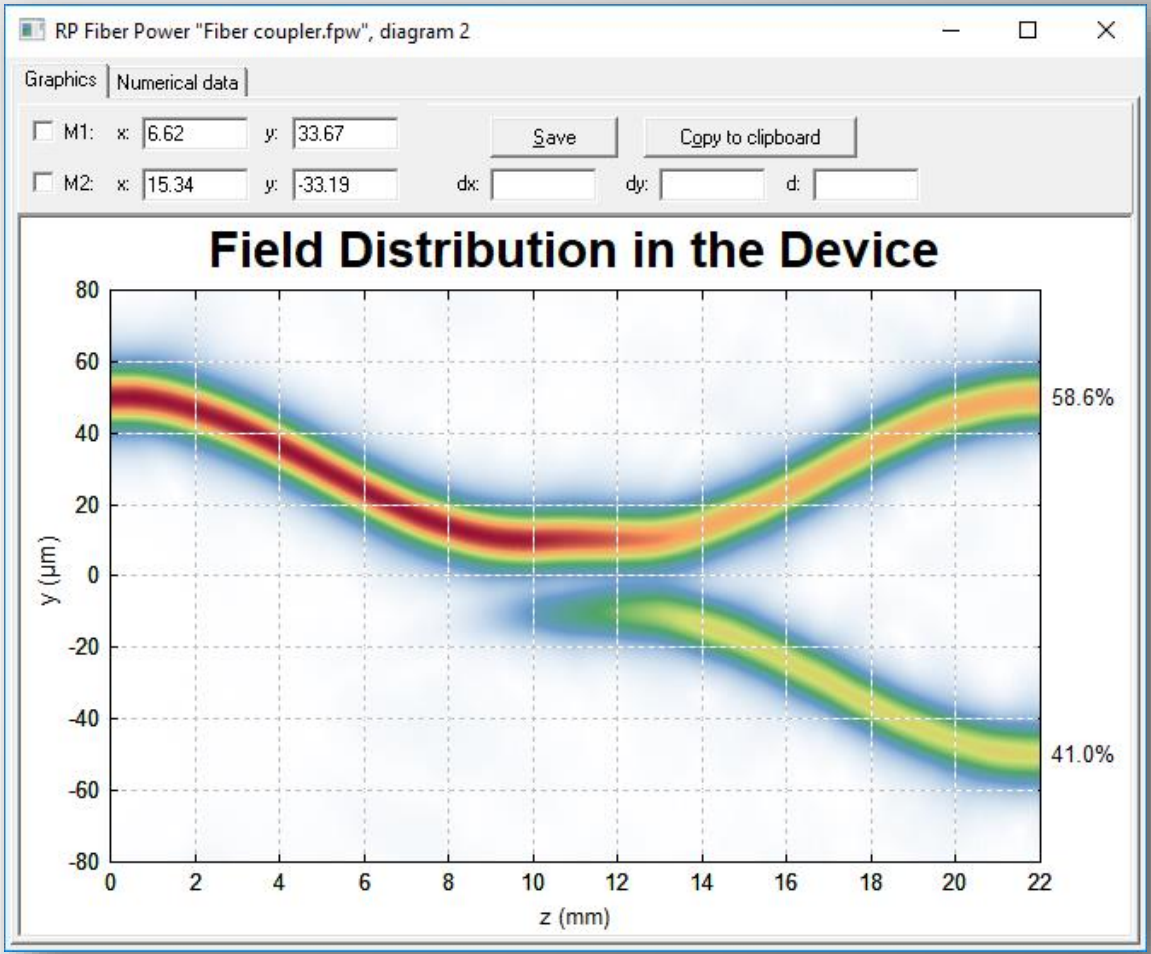
- **Code snippet library** for inserting frequently used parts of code
- **Parameter hints** for hundreds of functions
- **Multilevel undo/redo functionality**
- **Syntax highlighting** for good readability of code
- **Integrated syntax checker**
- Conveniently modify indentation of code blocks
- **Automatic code formatting** for consistent formats
- Setting of **breakpoints** for easy debugging



The User Interface (12)

Graphical output windows

- high-quality graphics, directly usable for publications:
  copy to clipboard or save to file
- can make animated graphics
- adjustable resolution
- markers for doing measurements
- export of numerical data



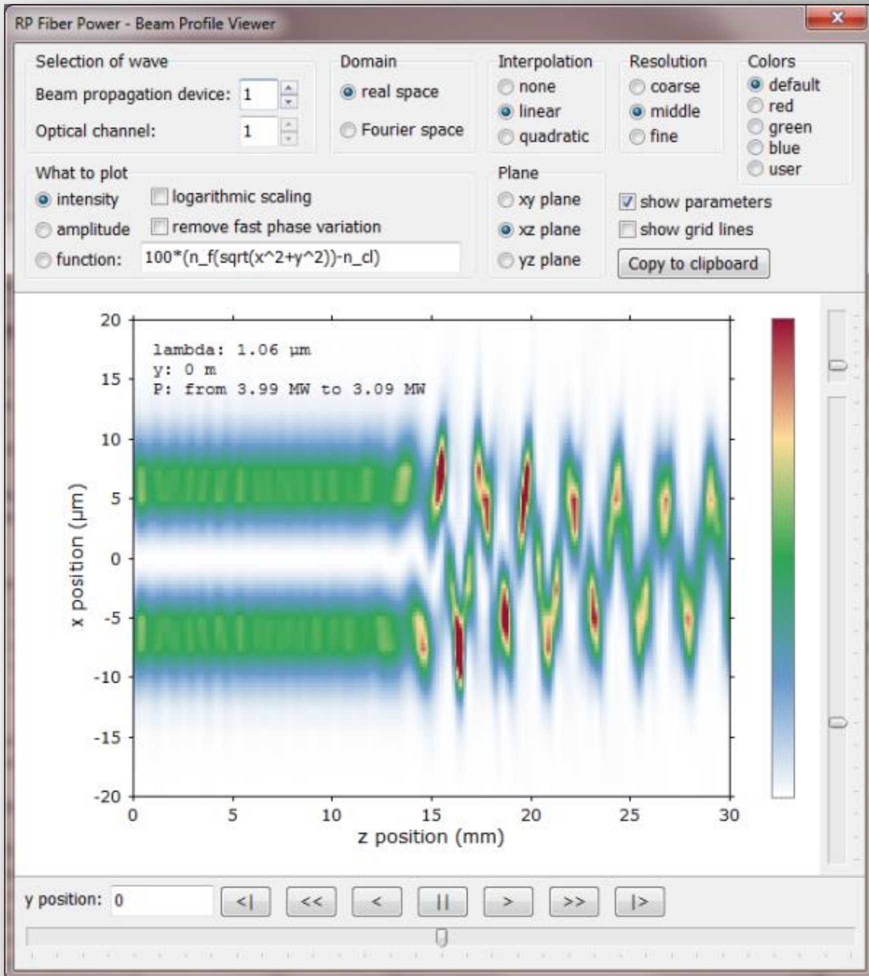
Also have flexible options for generating output in text form!

Put that into diagrams or files as you like.

The User Interface (13)

Interactive beam profile viewer

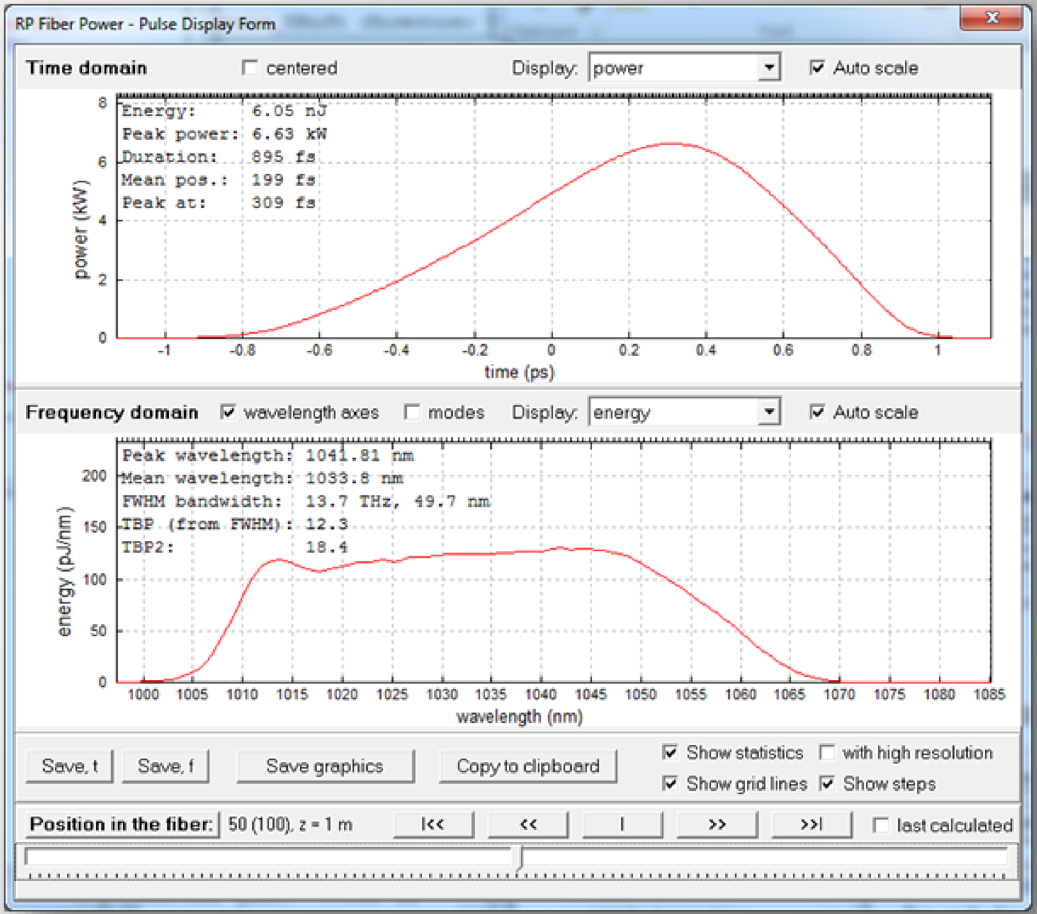
- Inspect calculated beam profiles.
- Switch between different wavelength components, displayed with different colors.
- Show profiles in xy, xz or yz plane.
- Change scaling or use logarithmic display in order to reveal weak satellites.
- Get parameters like center position and beam width displayed.



The User Interface (14)

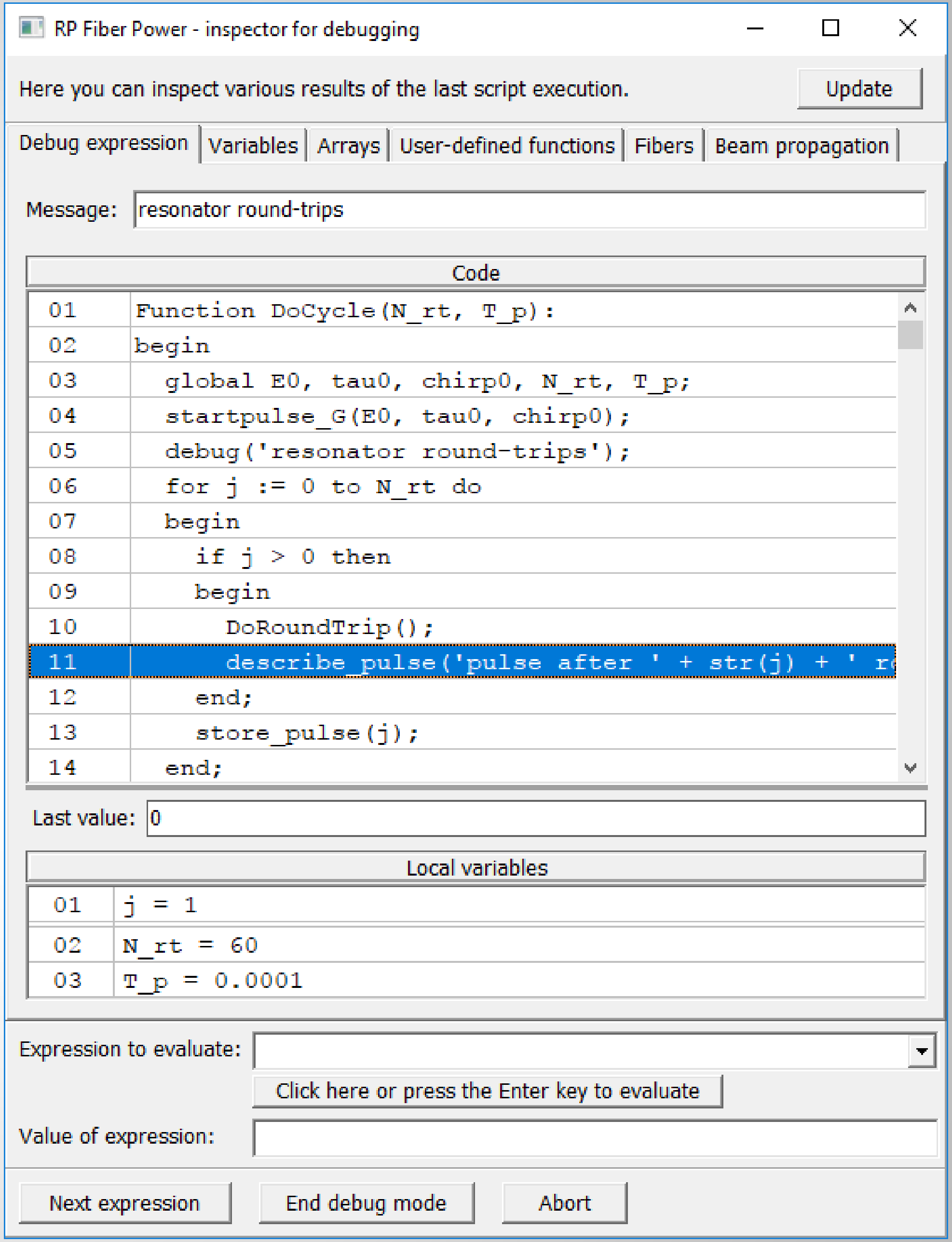
Interactive pulse display window

- Browse the pulses along the fiber, or pulses stored in an array.
- Display a variety of properties in the time and frequency domain.
- Get pulse parameters such as energy, duration, peak power, bandwidth, time–bandwidth product, etc.



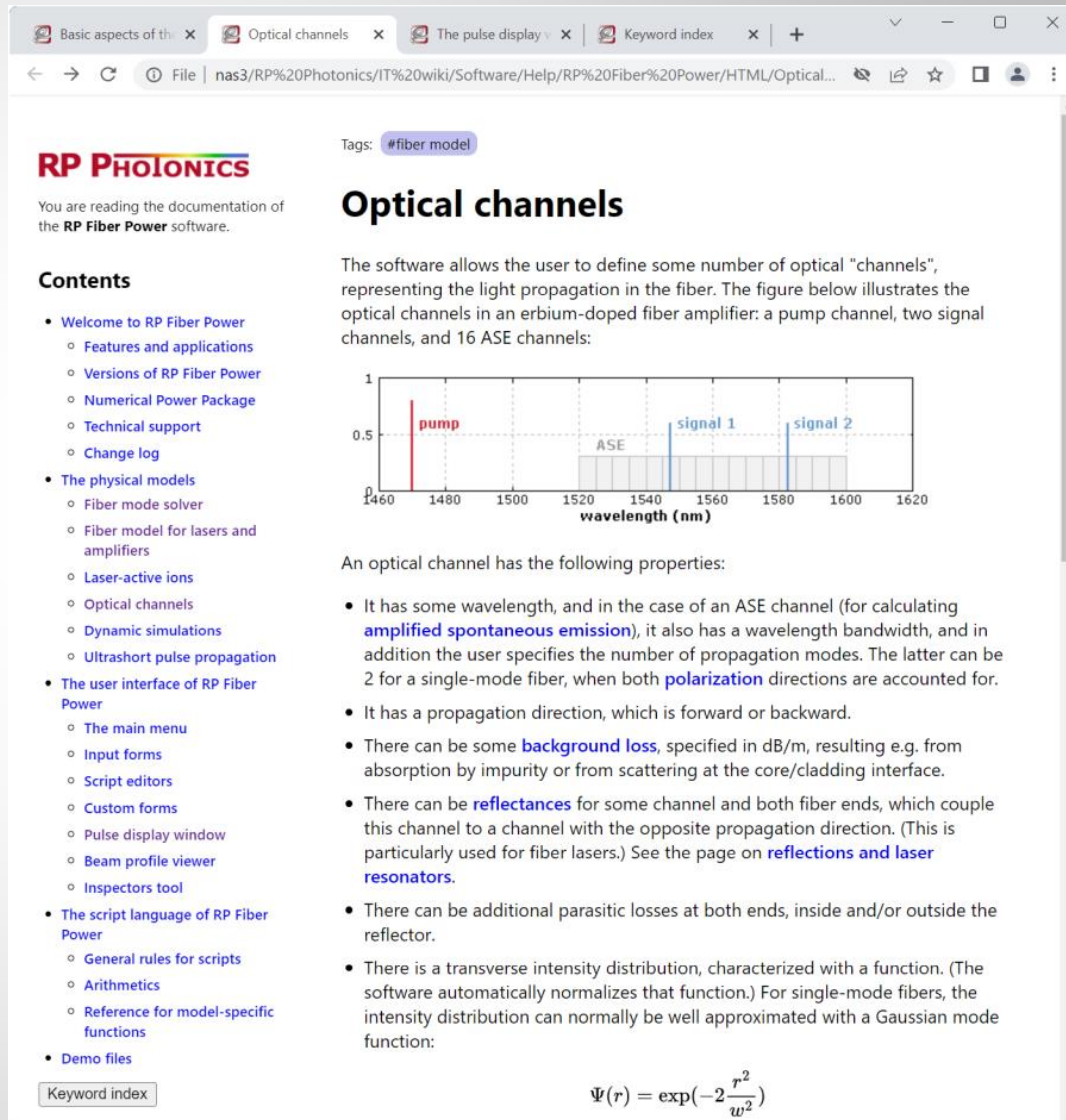
The Debugger

- In **debug mode**, inspect the detailed state of the system: global and local variables, arrays, functions, fiber definitions etc.
- Can evaluate any expression for monitoring further details.
- Can set **breakpoints** even within mathematical expressions! Also can use temporary and conditional breakpoints.
- Decide how to go forward: evaluate another step, continue executing normally, or abort the execution.



Documentation

- comprehensive **PDF manual**
- detailed **interactive help system** (displaying content in your web browser)
- comprehensive explanations of the used physical models, under-lying assumptions, details of the script language, etc.
- dozens of **demo files**, demonstrating many different possibilities
- detailed explanations also for each Power Form

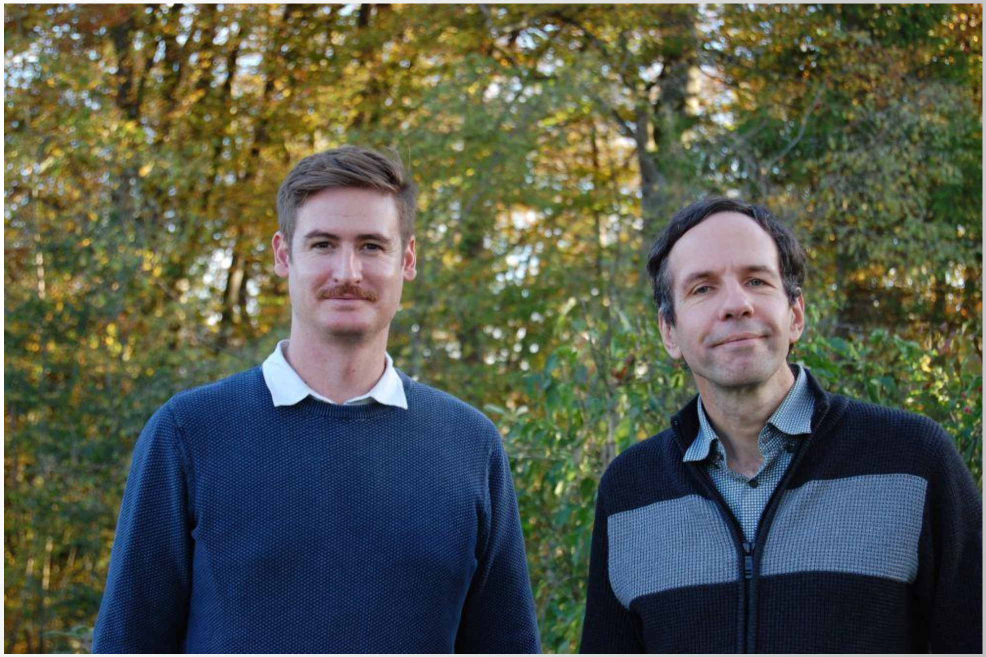


Technical Support

Any remaining technical issues can be addressed with the technical support:

The price for a **commercial user license** contains
8 support hours (non-commercial licenses: 4 hours).

The support is done by Dr. Paschotta, who is a distinguished expert in this area and has originally developed the software, and by Dr. Gareth Moore. They will make sure that you become another very satisfied user of the software!



Note that RP Photonics also offers technical consultancy.

Can I Afford This Software?

Sure, a high-quality software product including competent support from a top expert costs some money.

Anyway, the better question is:

Can I afford *not* to have a powerful software tool, i.e.,

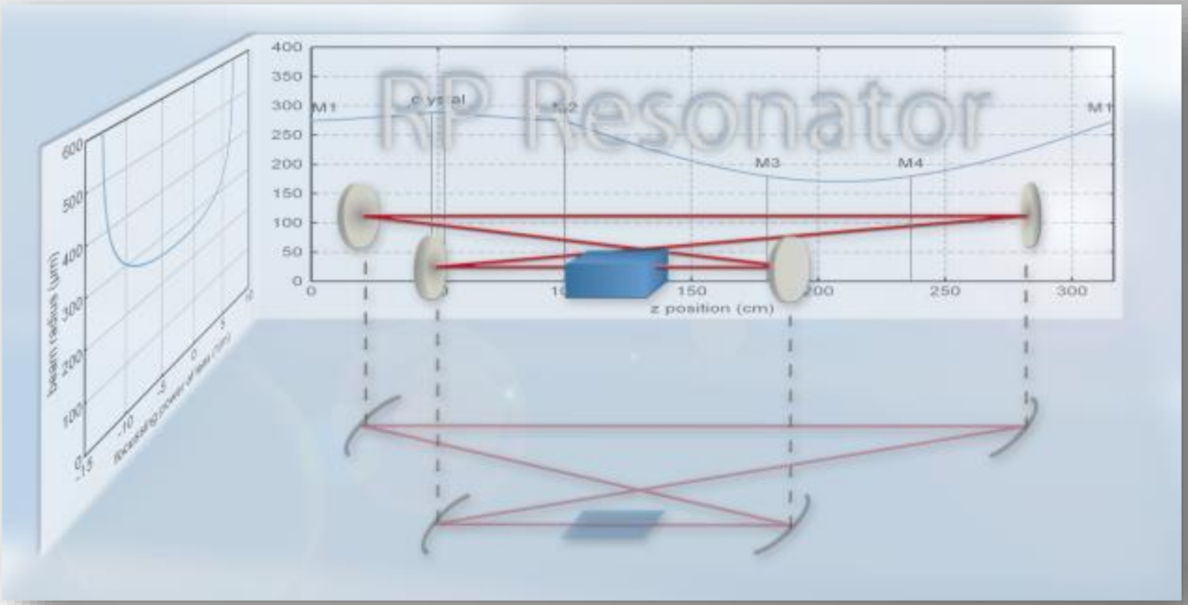
- to muddle through with insufficient tools?
- to use trial & error, wasting time and materials?
- to let customers wait while my competitors sell their products?

The **RP Fiber Power** software will give a boost to your productivity! Also, your employees or students will become productive sooner when they acquire a deep understanding by playing with this software.

Other Software from RP Photonics

RP Resonator:

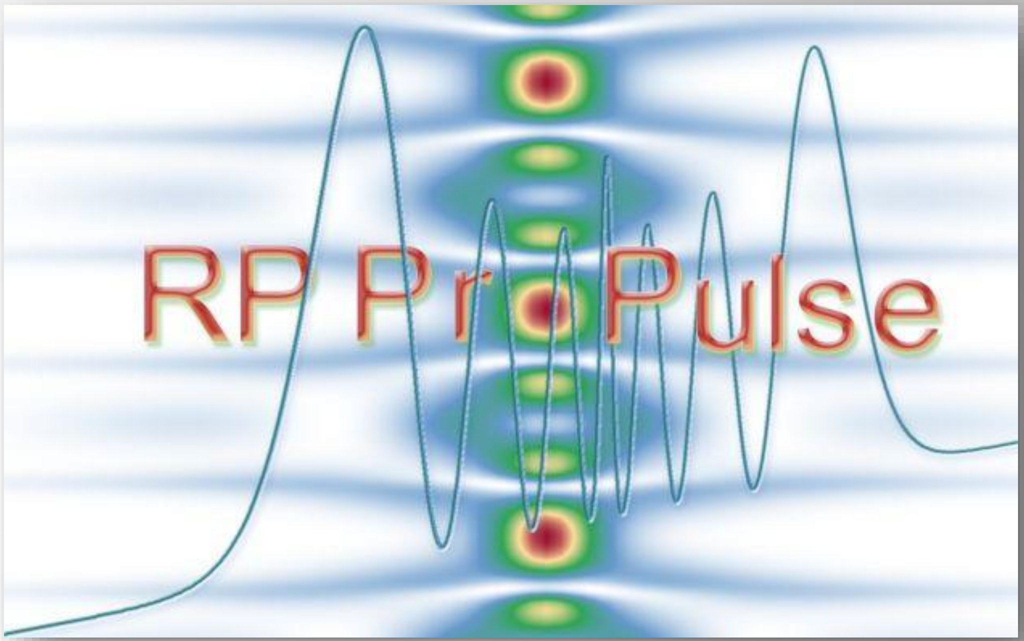
- design of optical resonators for lasers, OPOs, filters, etc.
- can fully parameterize the designs
- powerful script language for an enormous flexibility
- can do most sophisticated analysis and optimizations



See a detailed description: www.rp-photonics.com/rp-resonator.html

Other Software from RP Photonics

RP ProPulse:

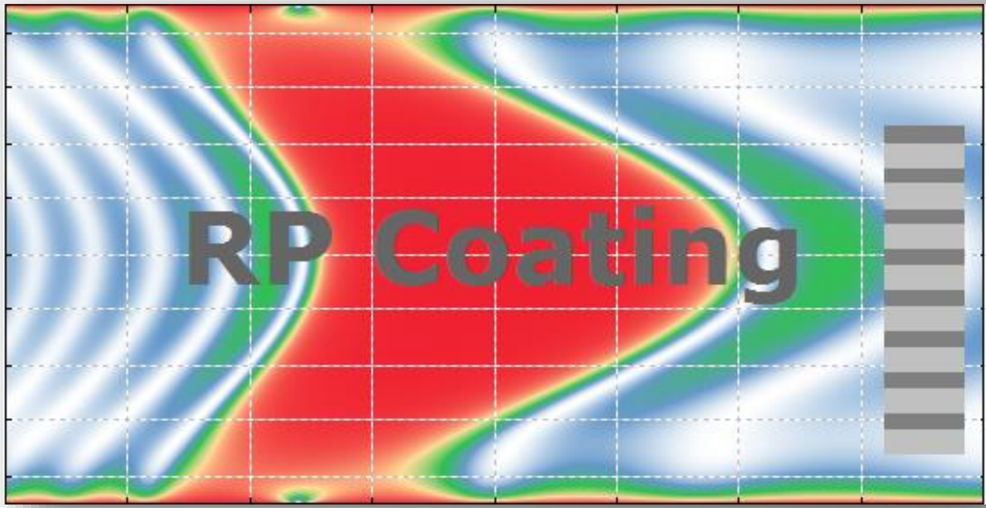


- simulates the propagation of ultrashort pulses e.g. in mode-locked lasers or sync-pumped OPOs
- can include laser gain, parametric gain, SHG, Kerr and Raman effect, chromatic dispersion, etc.
- pulse display window
- can do most sophisticated analysis and optimizations

See a detailed description: www.rp-photonics.com/rp_propulse.html

Other Software from RP Photonics

RP Coating:



- analysis of multilayer thin-film devices: laser mirrors, filters, anti-reflection coatings, dispersive mirrors, polarizers, SESAMs, VECSELs, …
- can fully parameterize designs
- read / write data from or to text files or binary files with arbitrary formats: read transmission spectra from a spectrometer, control a coating machine, etc.
- can do most sophisticated analysis and optimizations

See a detailed description: www.rp-photonics.com/rp_coating.html