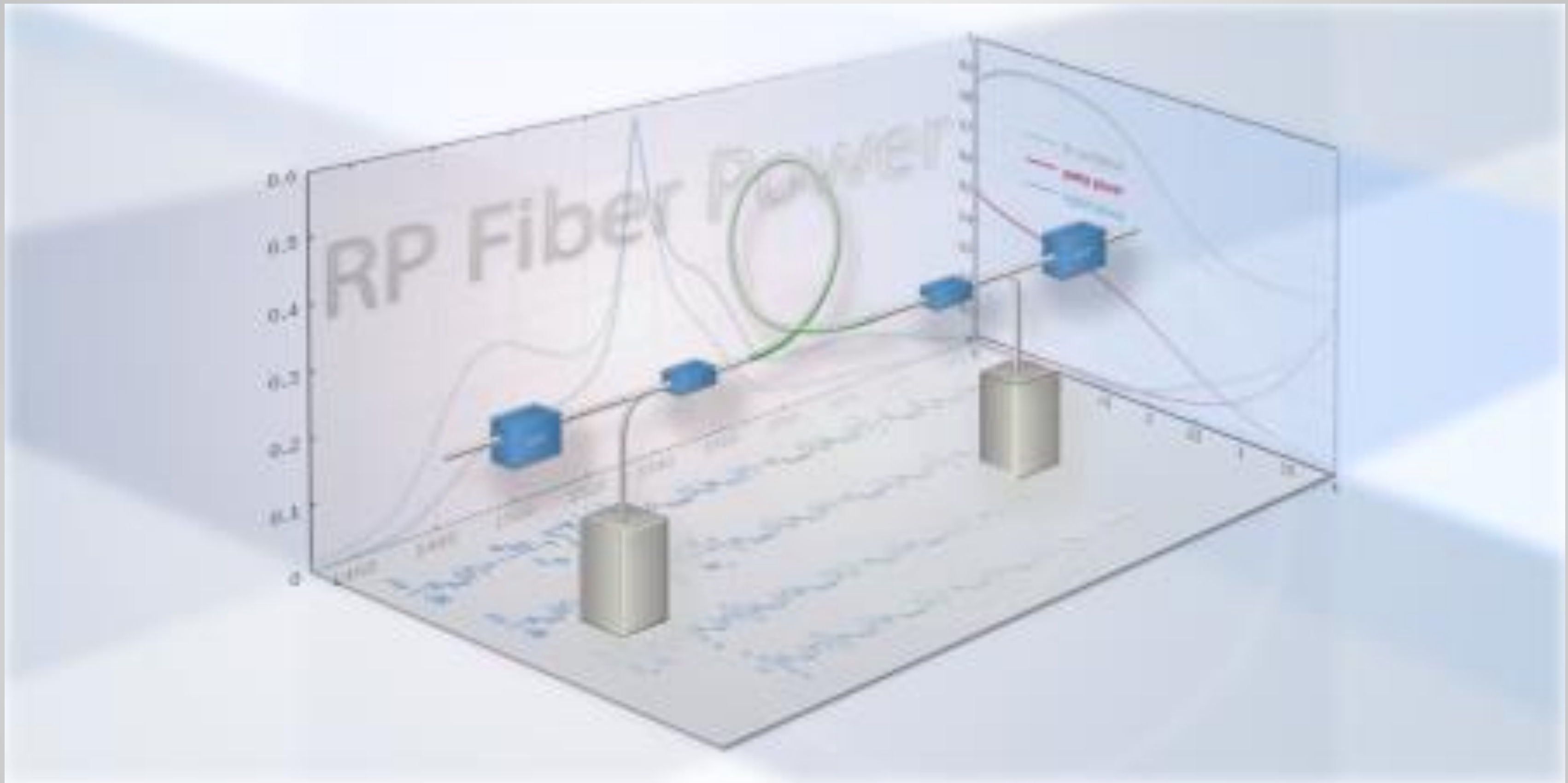
RP Fiber Power V7



a software product of

RP Photonics Consulting GmbH

www.rp-photonics.com/fiberpower.html

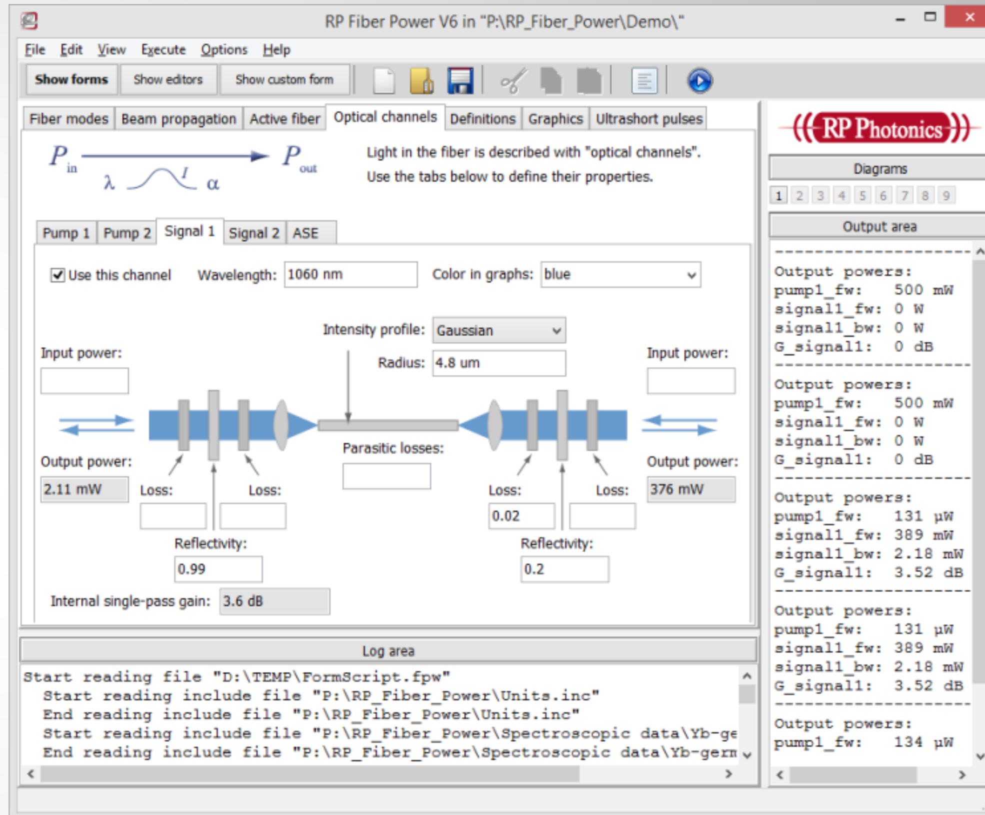
What are Simulations in Fiber Optics Good For?

- 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.**

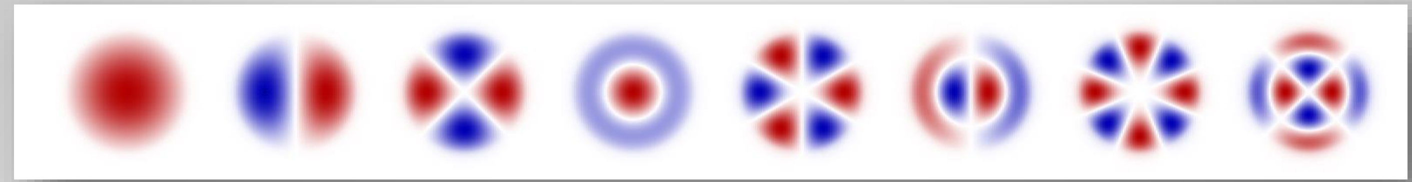
Profit From Powerful Software

- 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.**

Calculation of Fiber Modes (1)

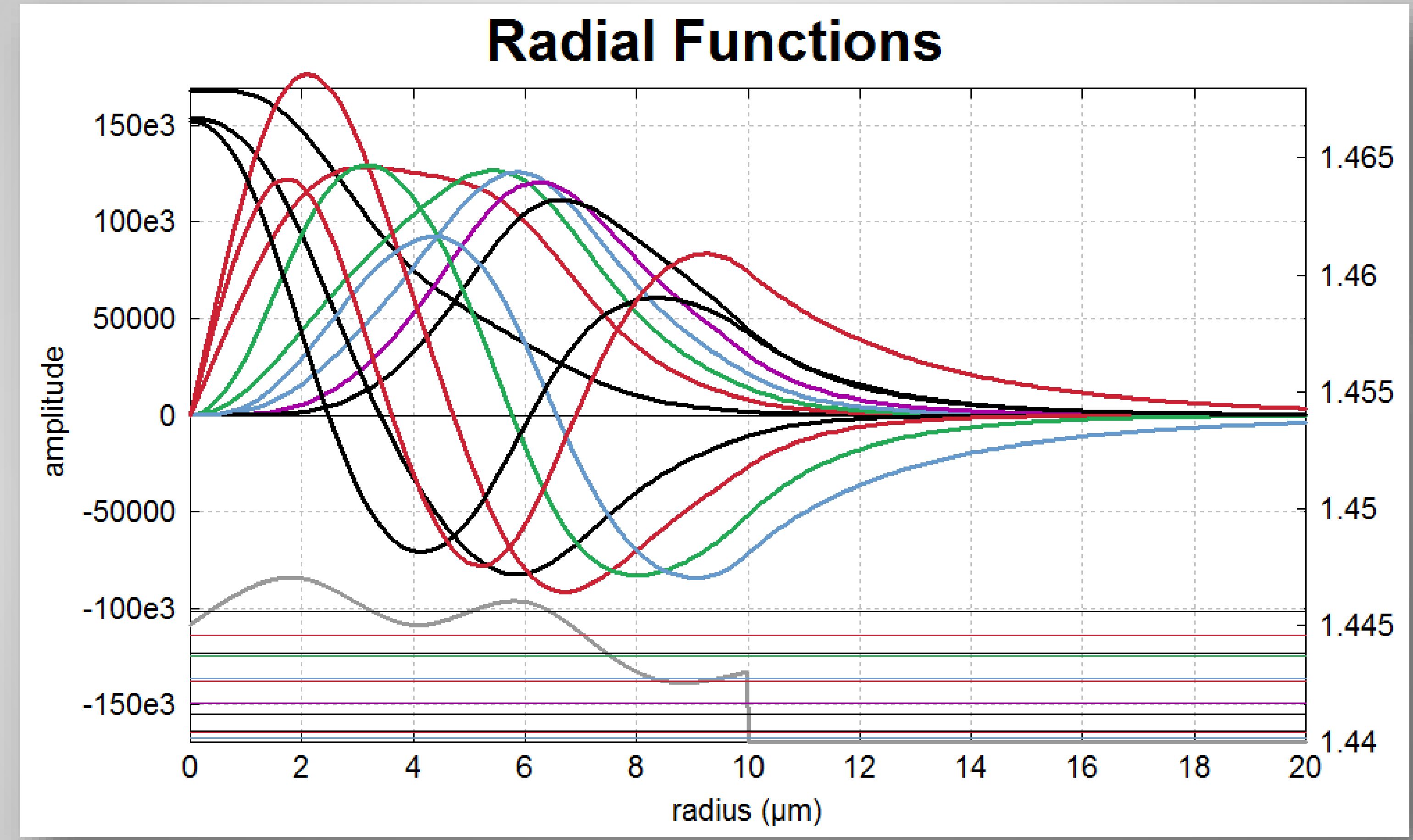


From a given refractive index profile, the integrated mode solver calculates all guided modes (LP modes):

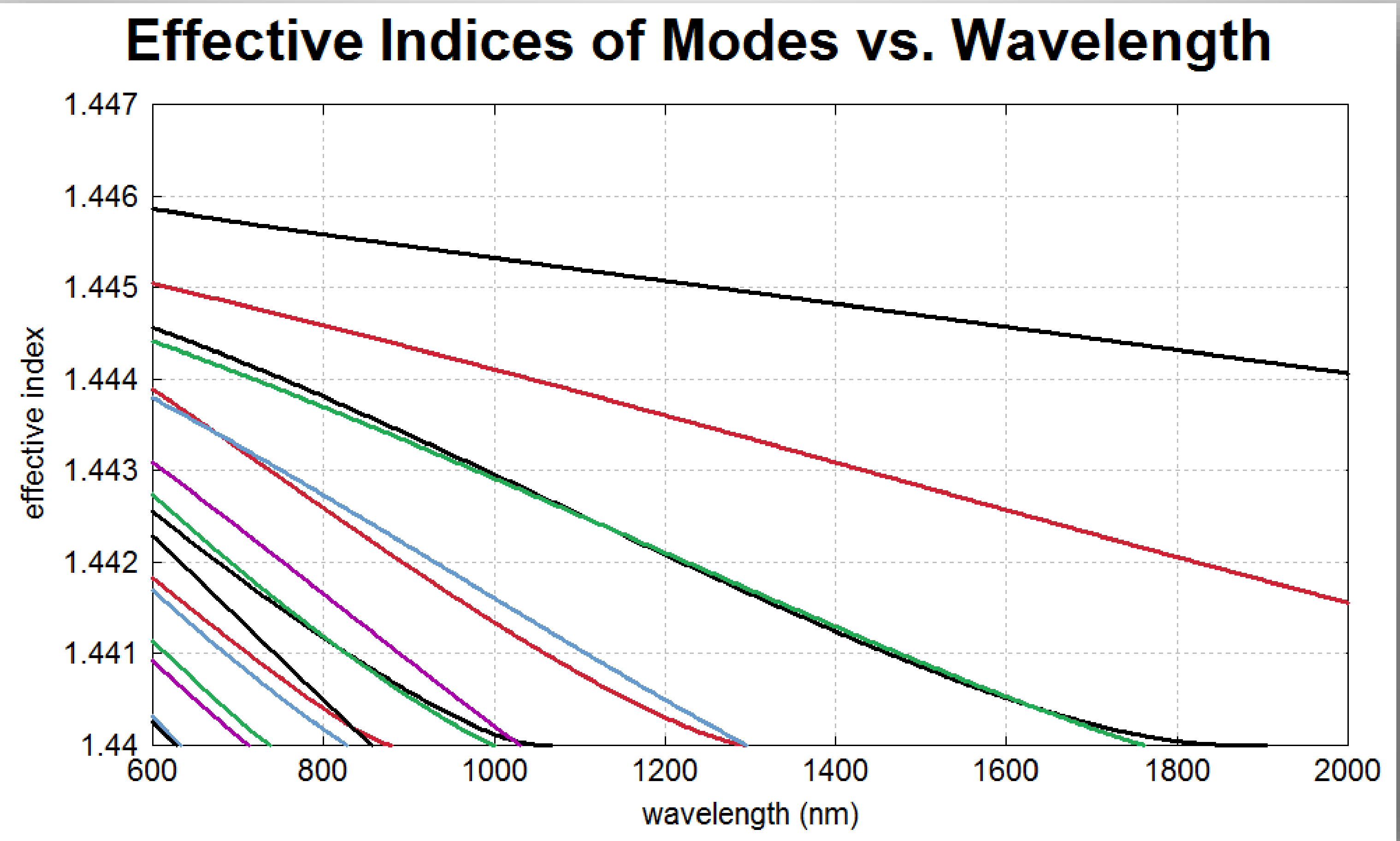
- amplitude and intensity profiles
- effective mode areas
- cut-off wavelengths
- effective refractive indices and group indices
- chromatic dispersion

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

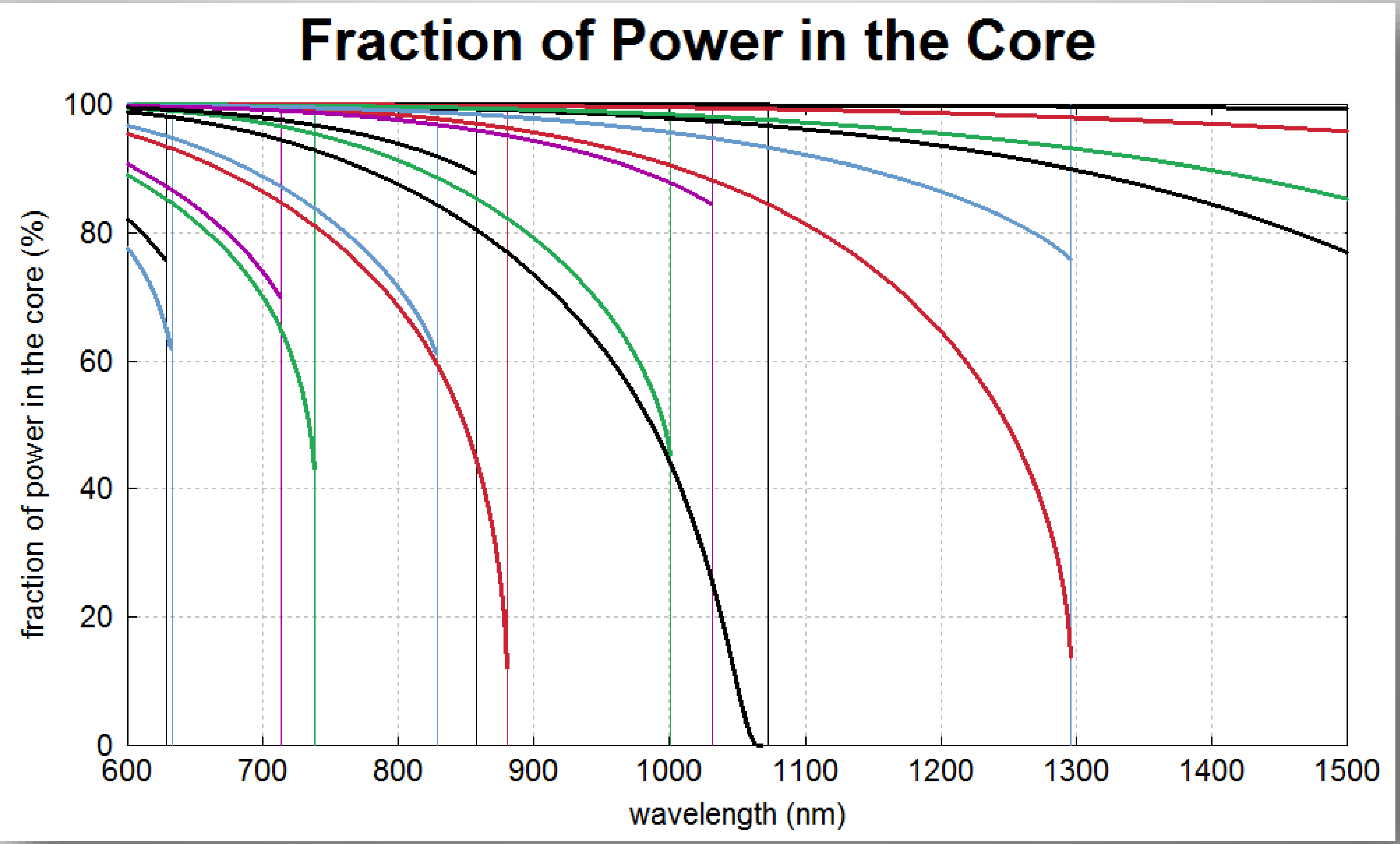
Calculation of Fiber Modes (2)



Calculation of Fiber Modes (3)

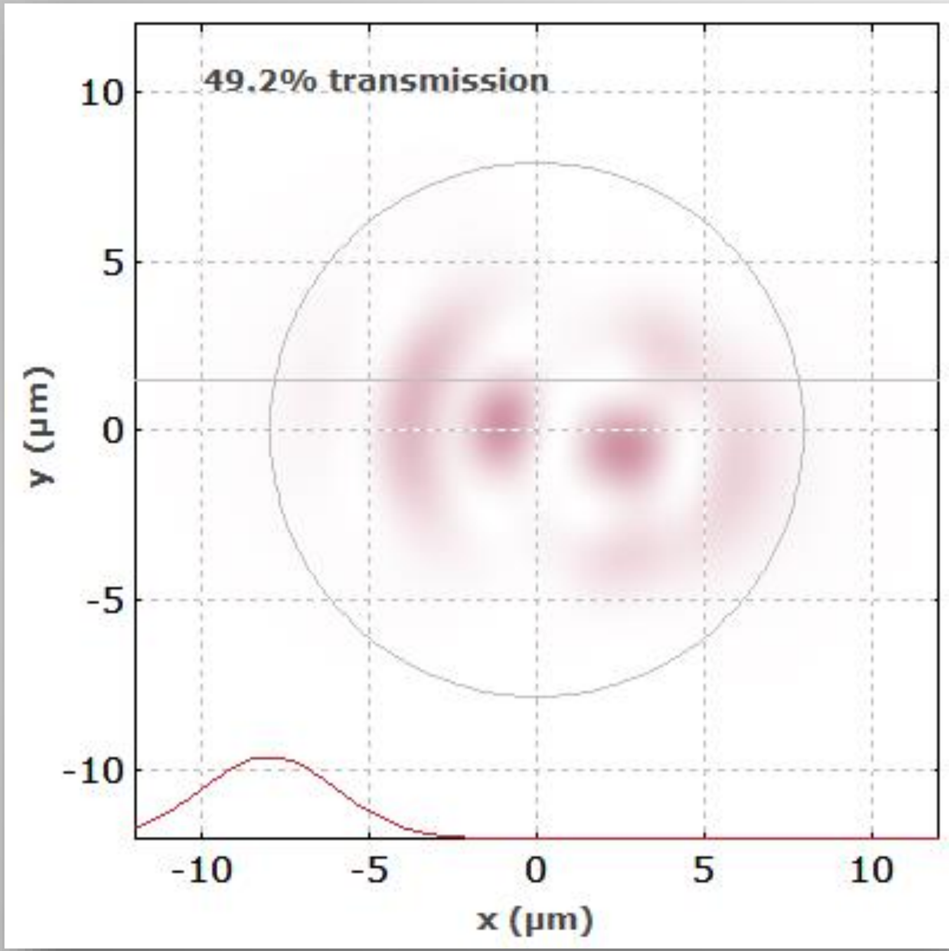


Calculation of Fiber Modes (4)



Calculation of Fiber Modes (5)

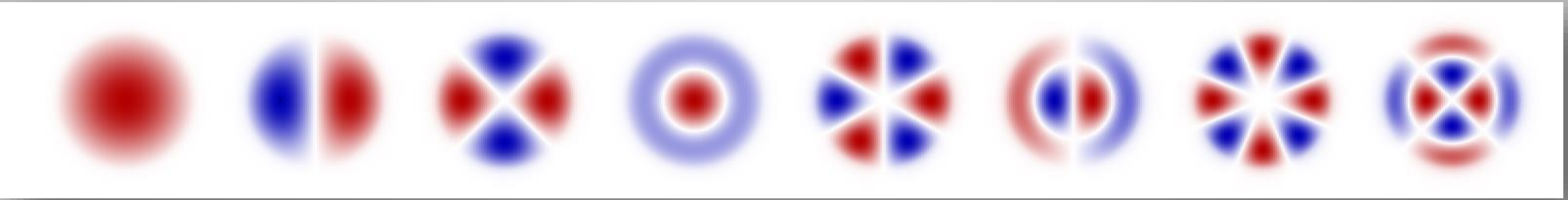
Example: Launching light into a multimode fiber



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)

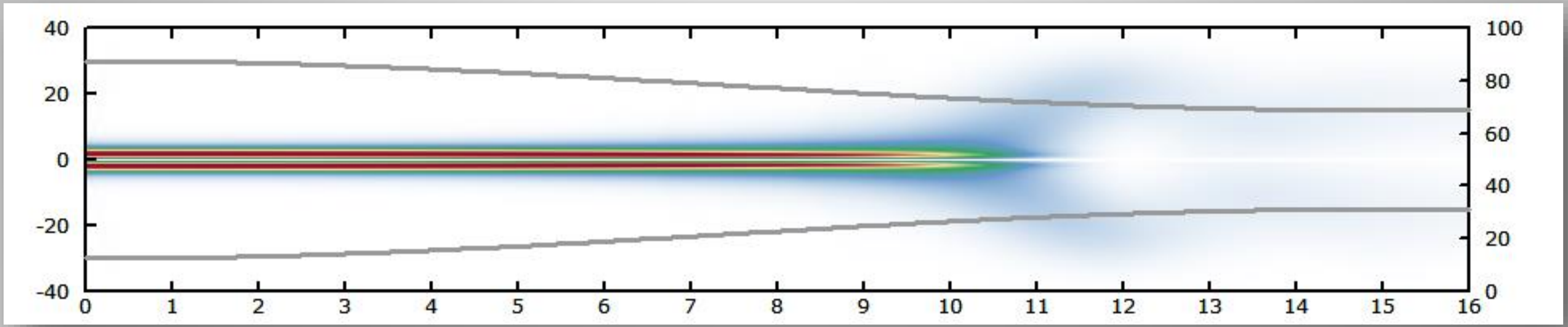


Applications:

- **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)

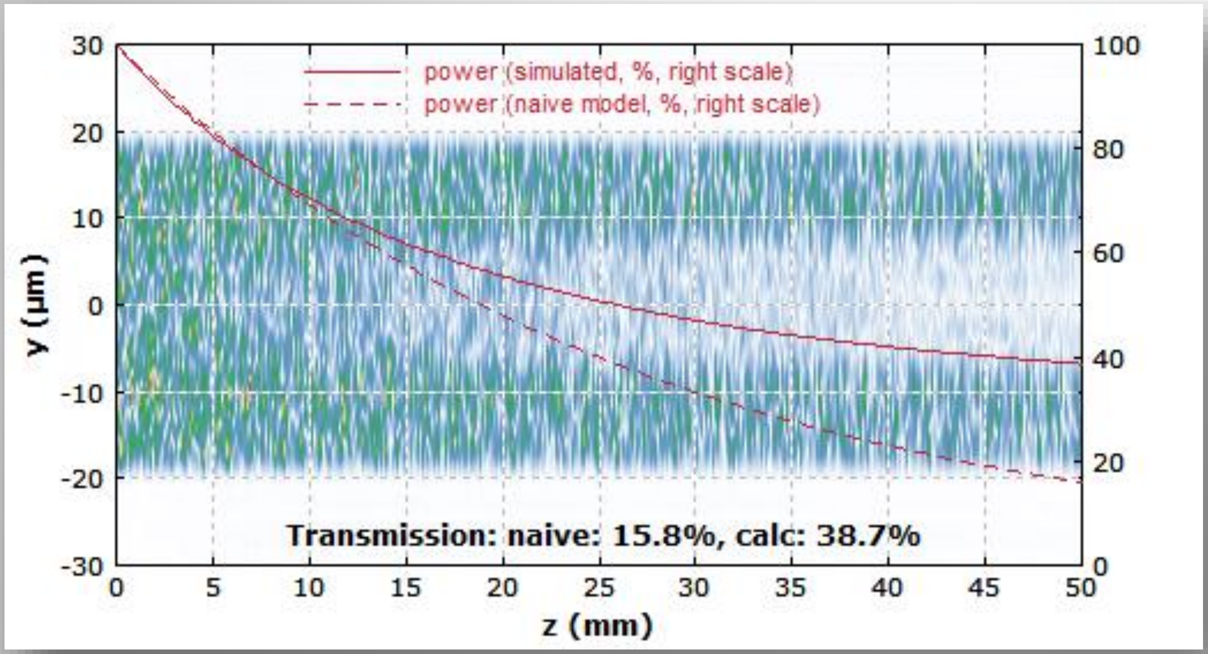


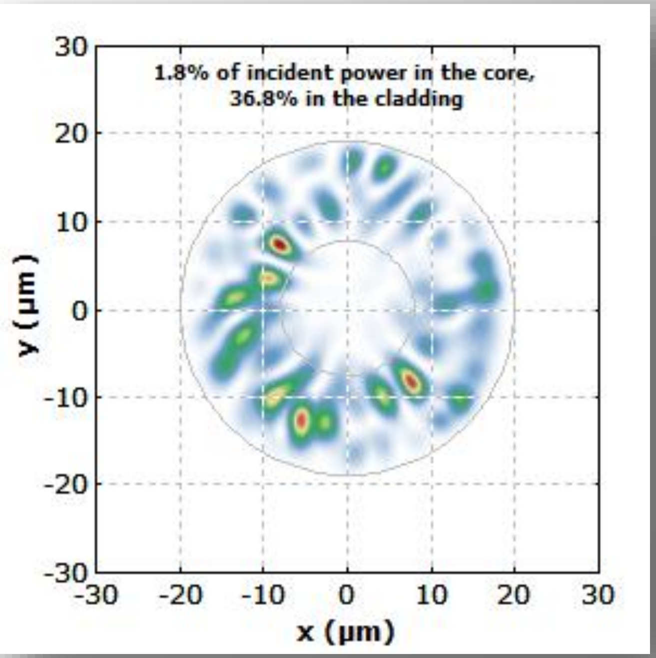
- Propagate arbitrary field distributions through fibers or other waveguides.
- Create structures as you like:
  may have tapered regions, variable bends, multiple cores, lossy regions, saturable laser gain, …
  → usable for double-clad fibers, fiber couplers, multi-core fibers, helical core fibers,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

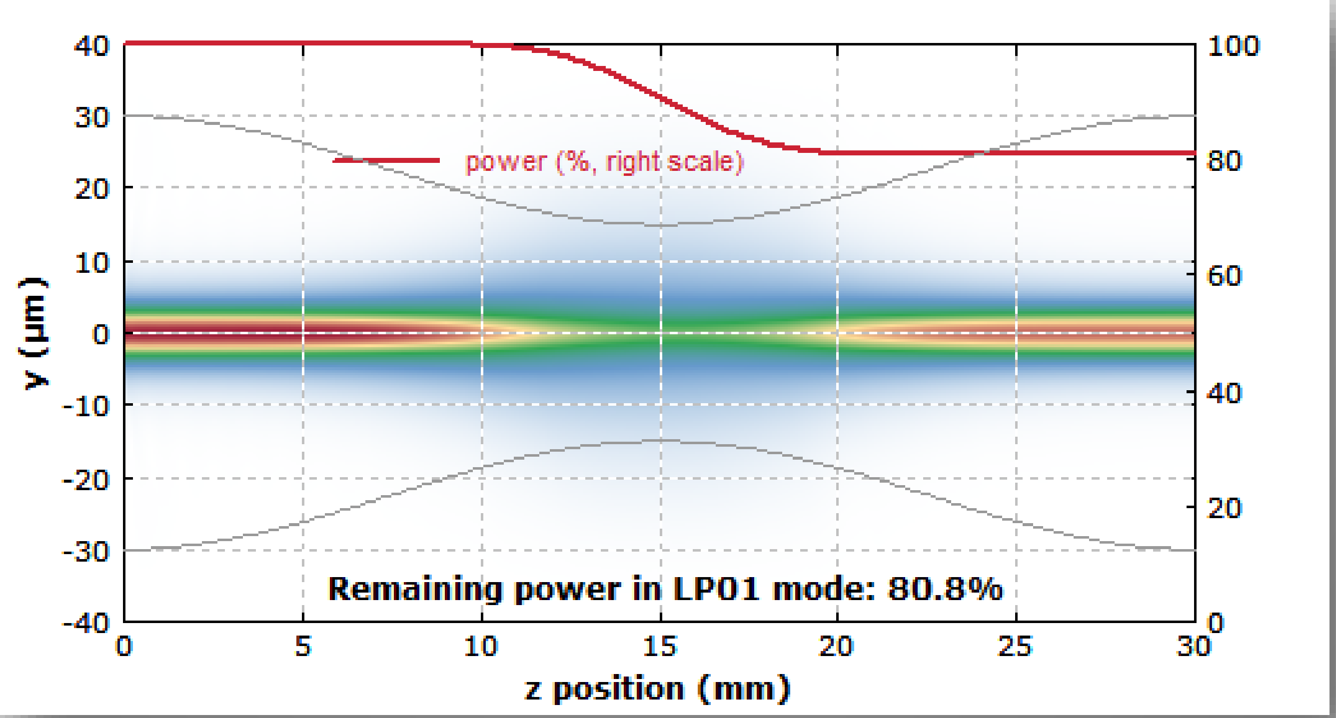




Numerical Beam Propagation (3)

Example: tapered fiber

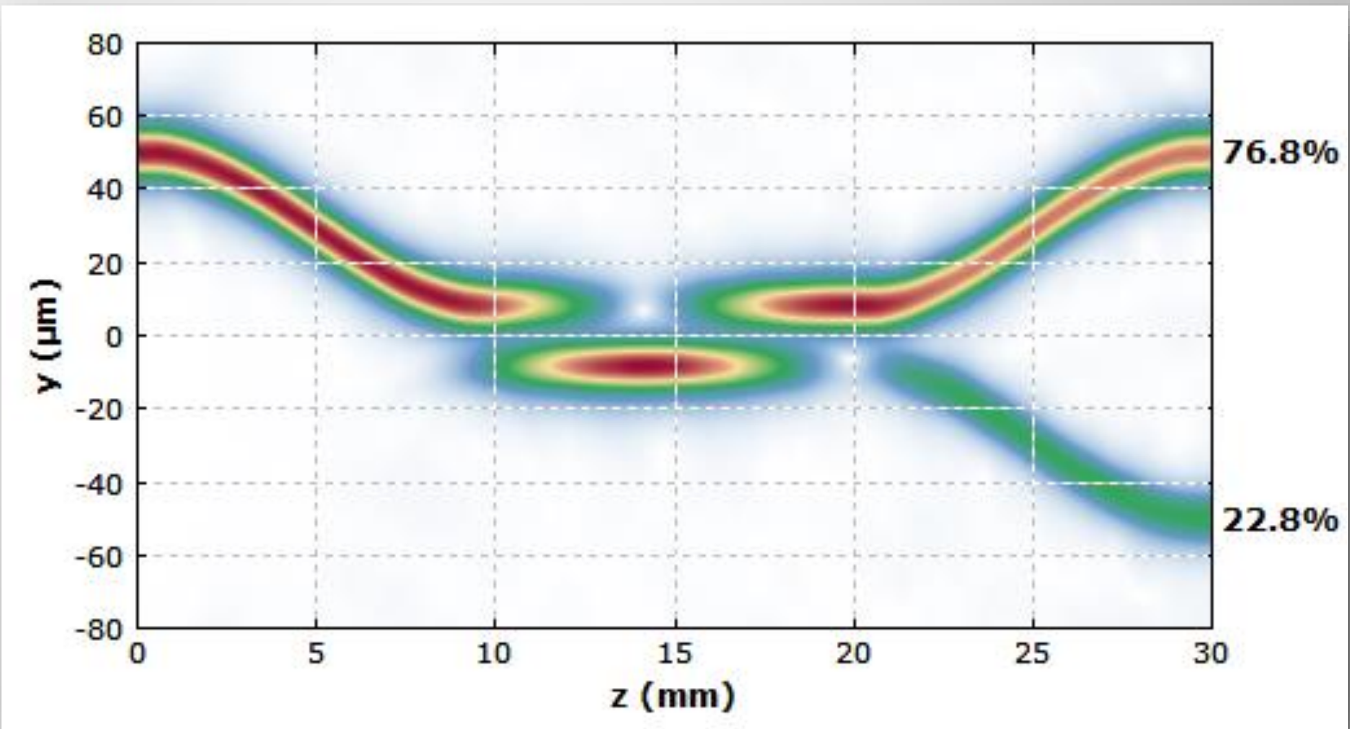
- Define a three-dimensional refractive index profile with a waveguide which gets narrower in some region.
- Study the wavelength- and mode-dependent losses.



Numerical Beam Propagation (4)

Example: fiber coupler

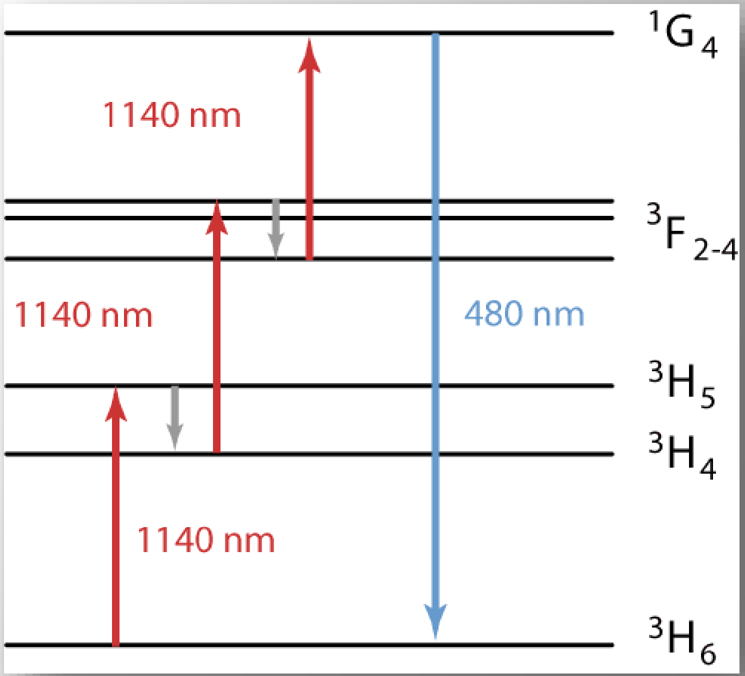
- Define a three-dimensional refractive index profile with two waveguides.
- Study evanescent field coupling. At long wavelengths, also get bend losses.



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.

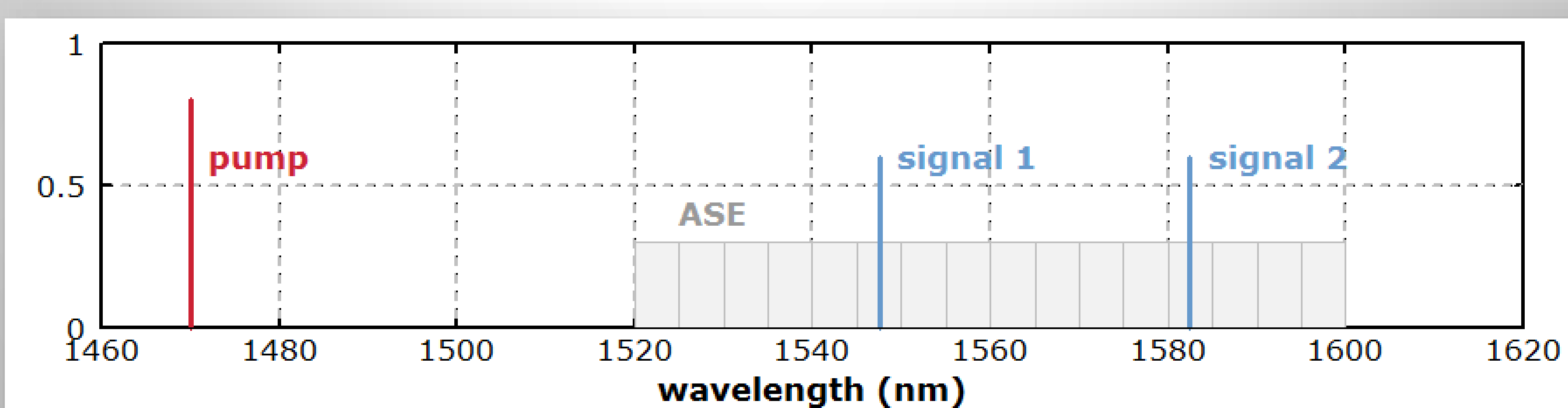
Calculation of Optical Powers (3)

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.



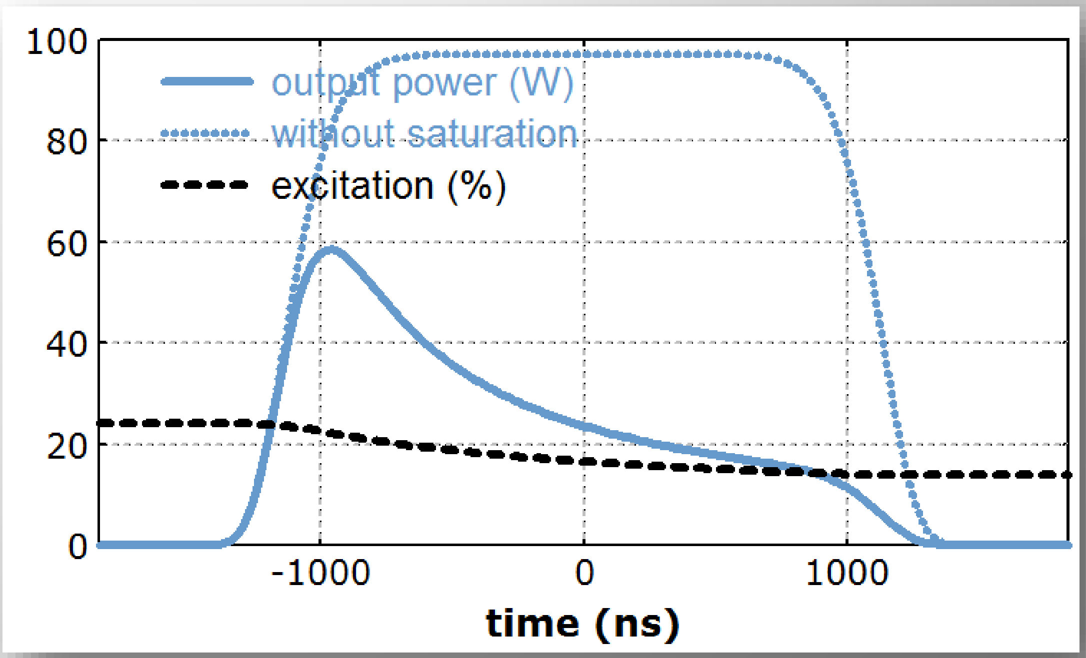
Calculation of Optical Powers (4)

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.

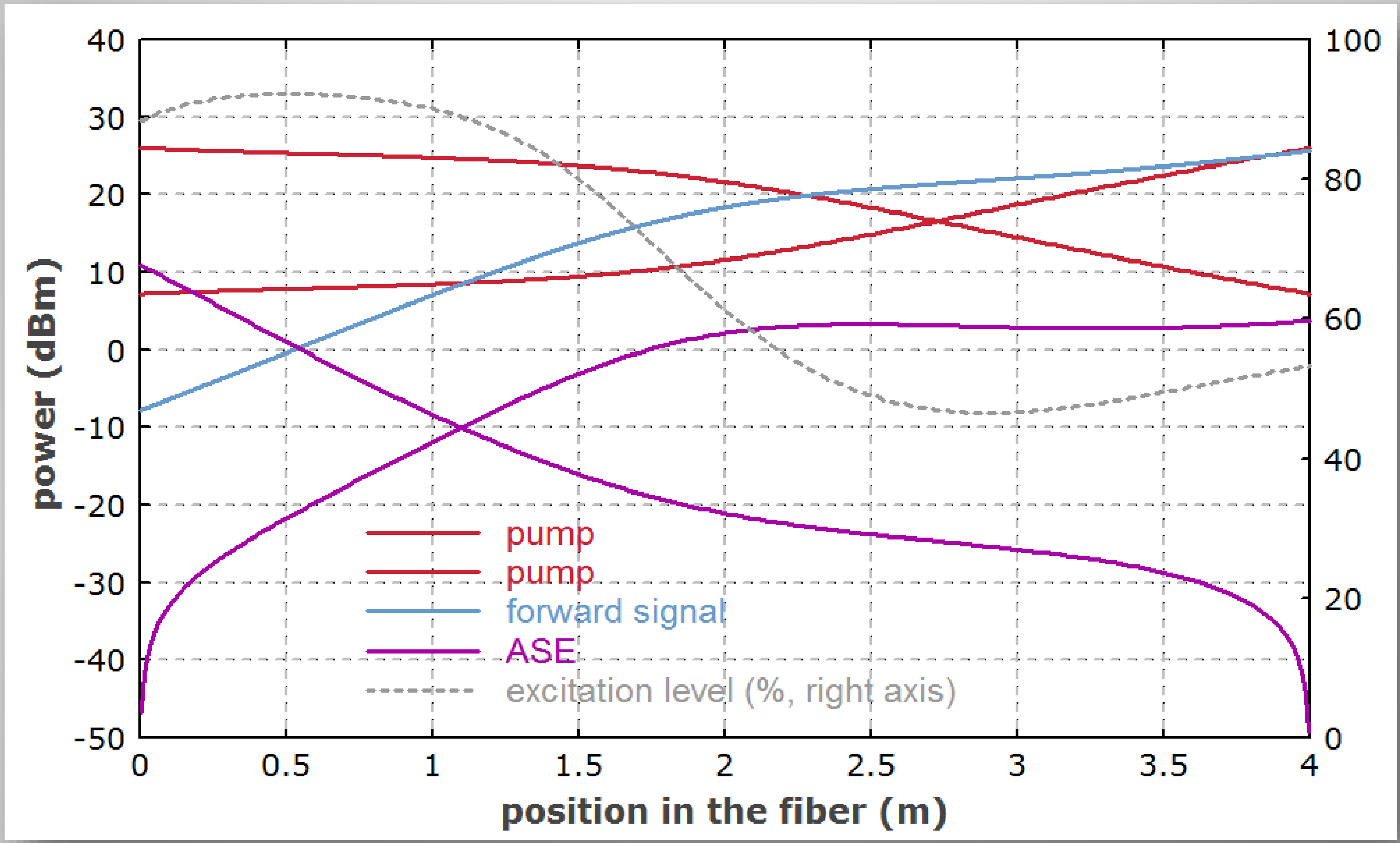
Applications:

- pulsed amplifiers
- Q-switched fiber lasers



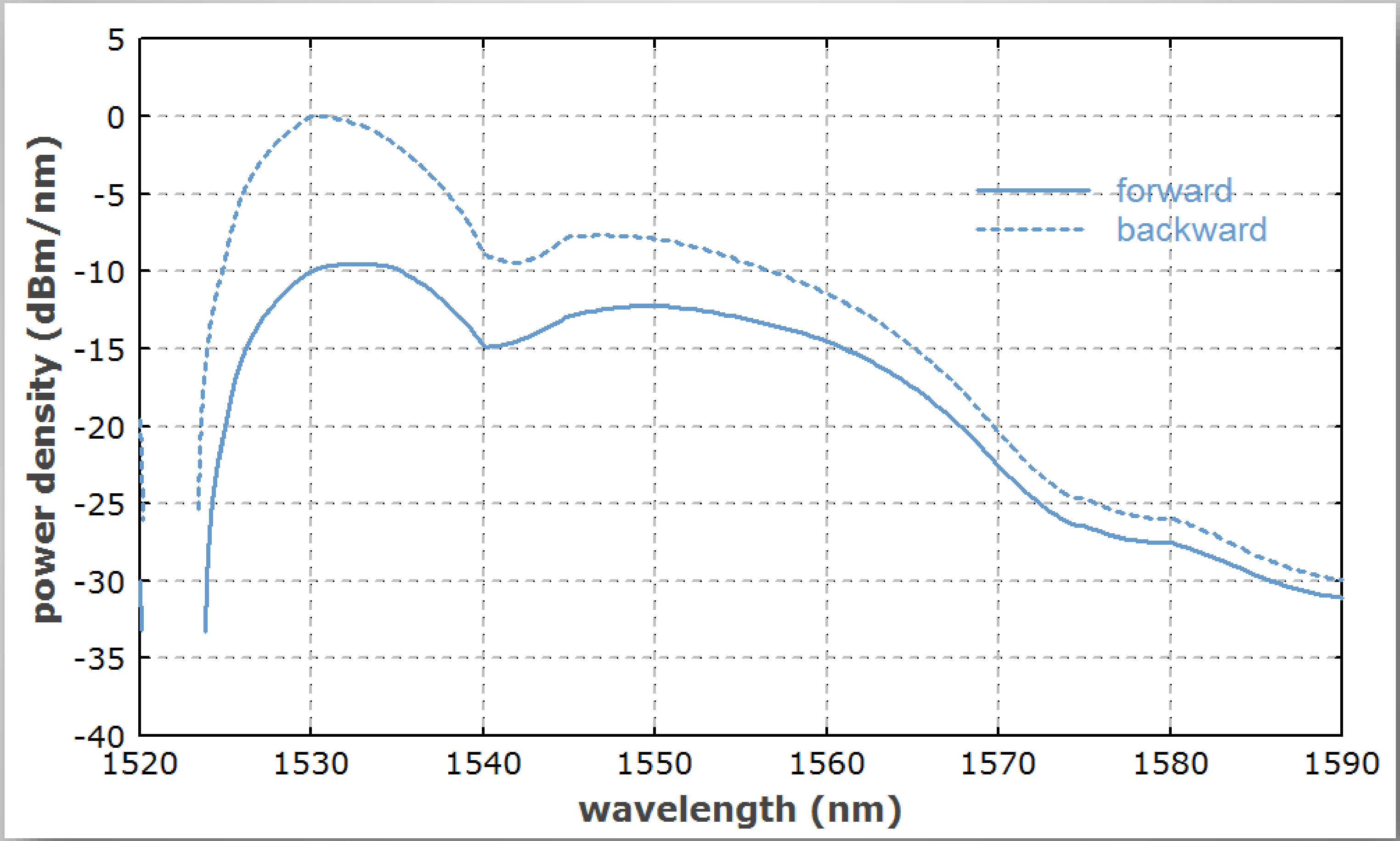
Calculation of Optical Powers (5)

Distribution of optical powers in an erbium-doped fiber amplifier



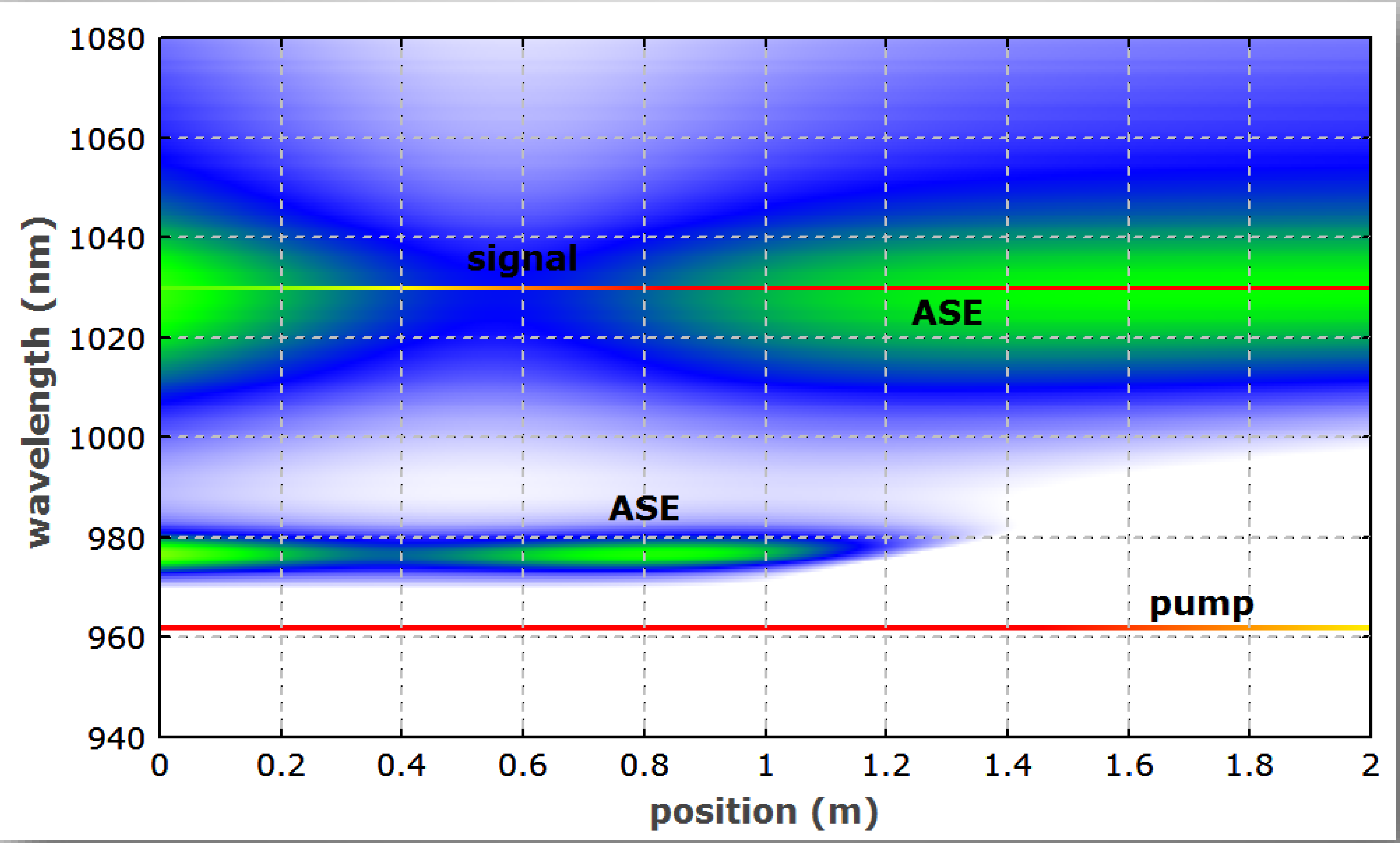
Calculation of Optical Powers (6)

ASE spectrum of an erbium-doped fiber amplifier



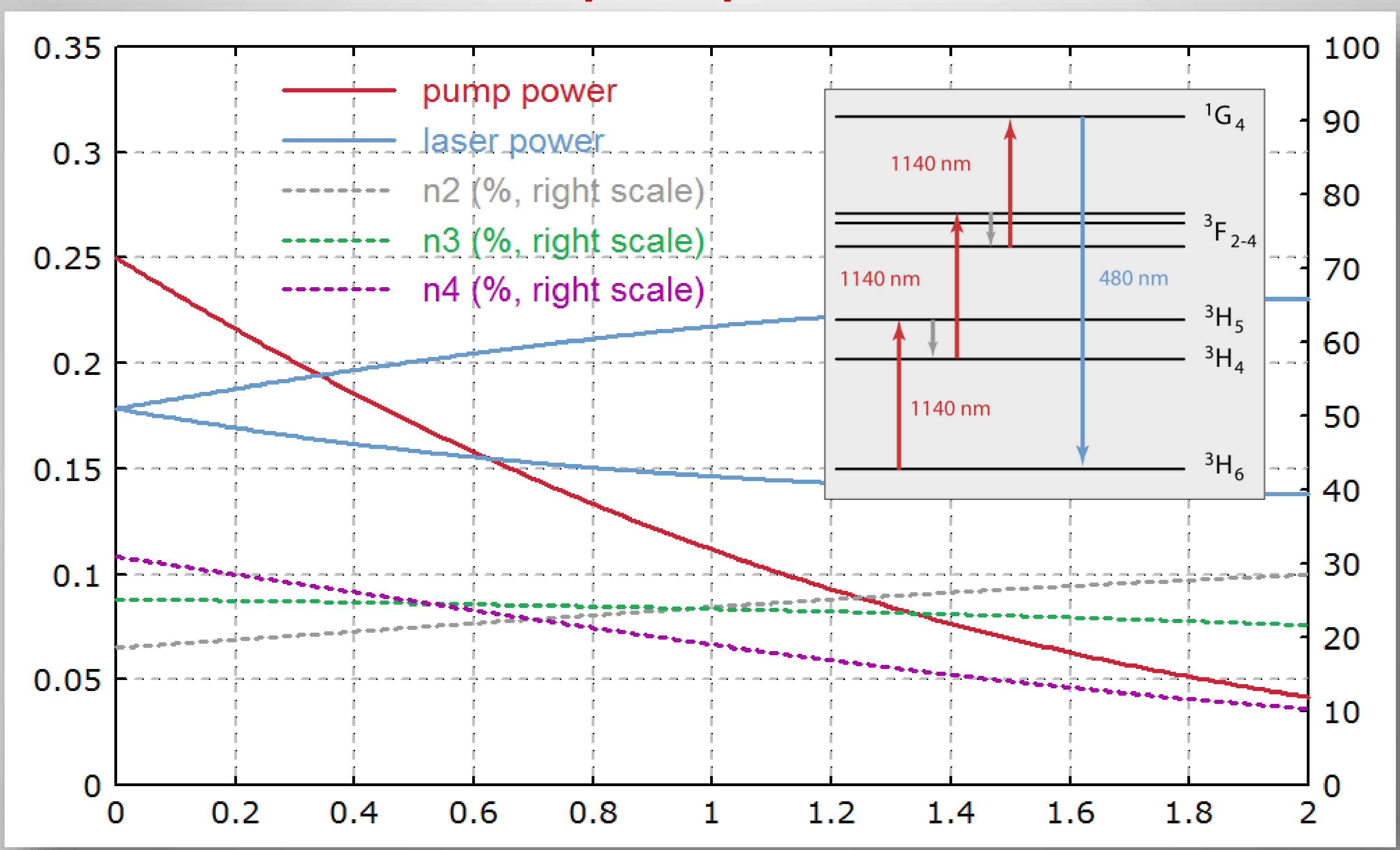
Calculation of Optical Powers (7)

ASE in ytterbium-doped amplifier



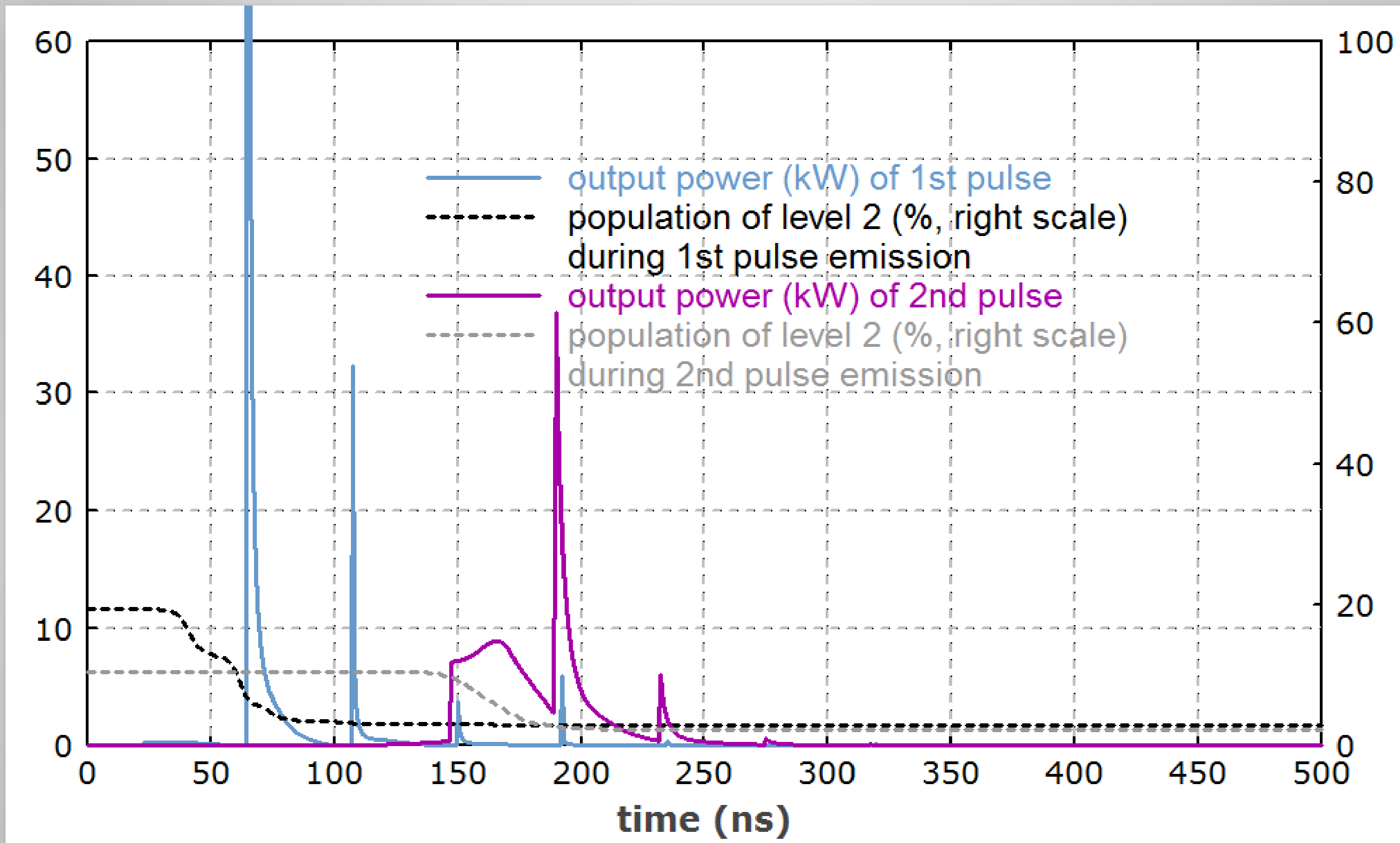
Calculation of Optical Powers (8)

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



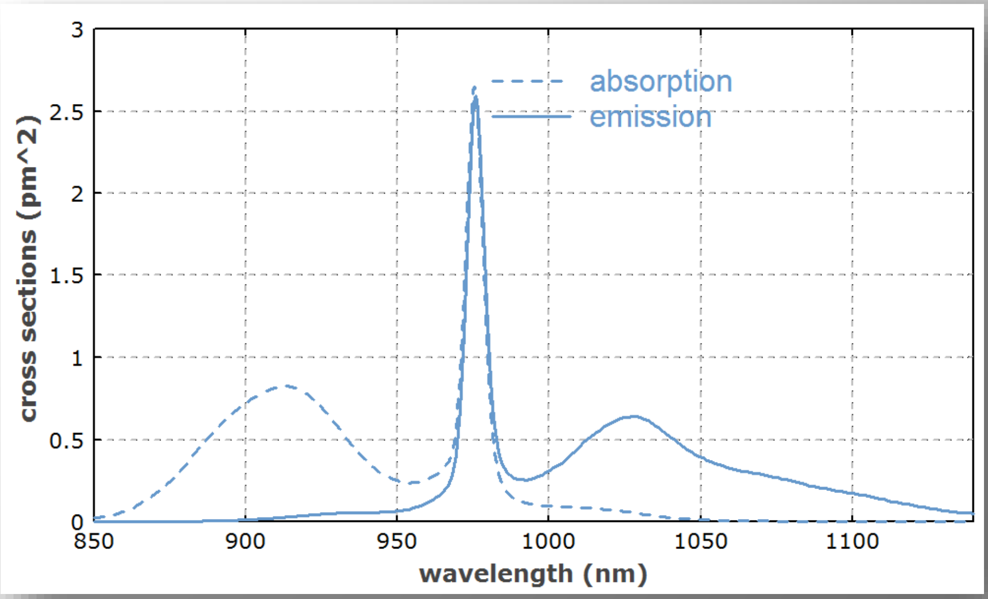
Calculation of Optical Powers (9)

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 measurements 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, sech2-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:

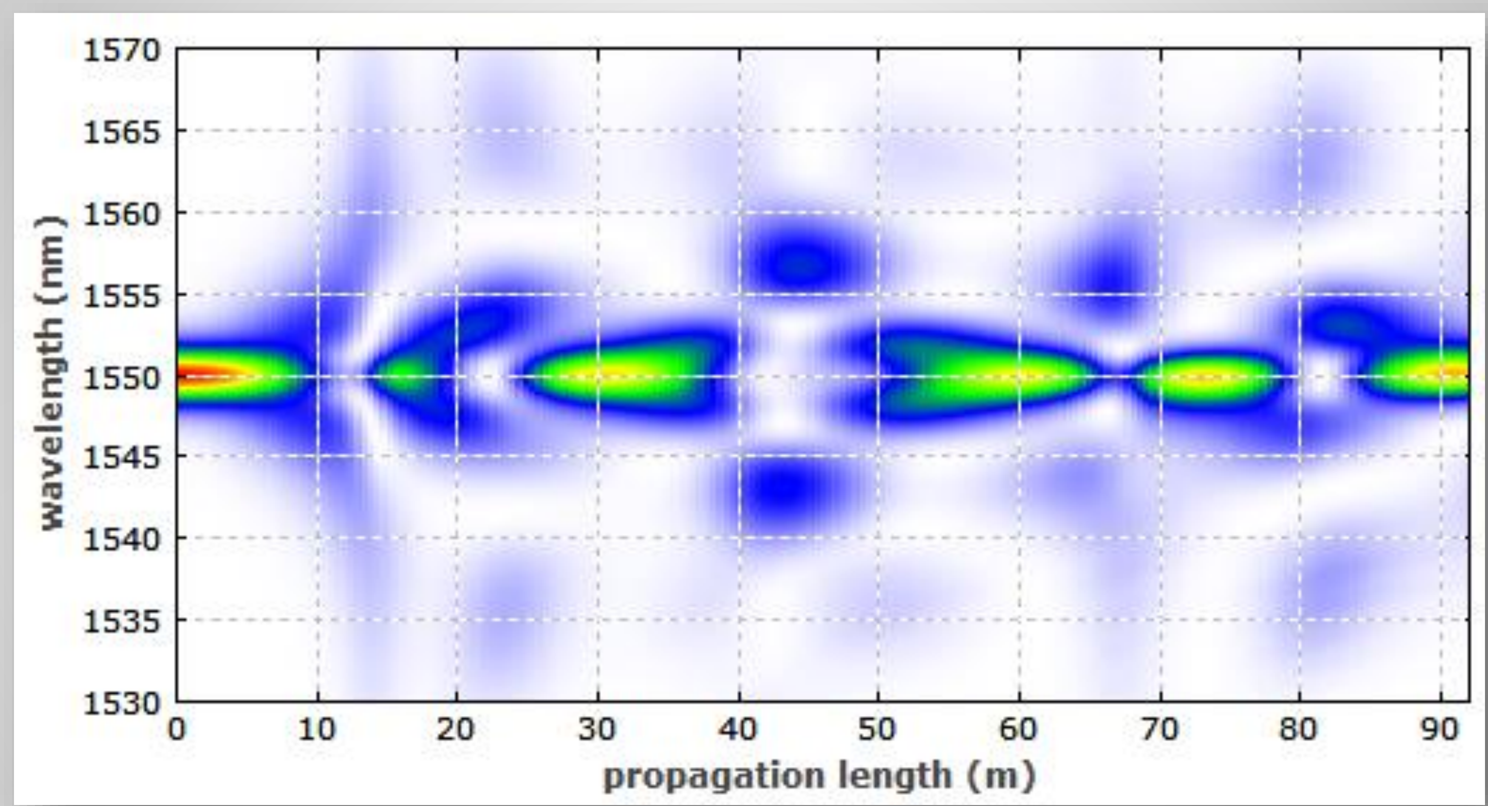
- Script language provides many dozens of **functions for retrieving all sorts of pulse properties**: pulse energy, peak power, peak position, pulse duration and spectral width (based on different definitions), amplitude profiles, spectral phase, autocorrelation, etc.
- Easy pulse inspection with the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

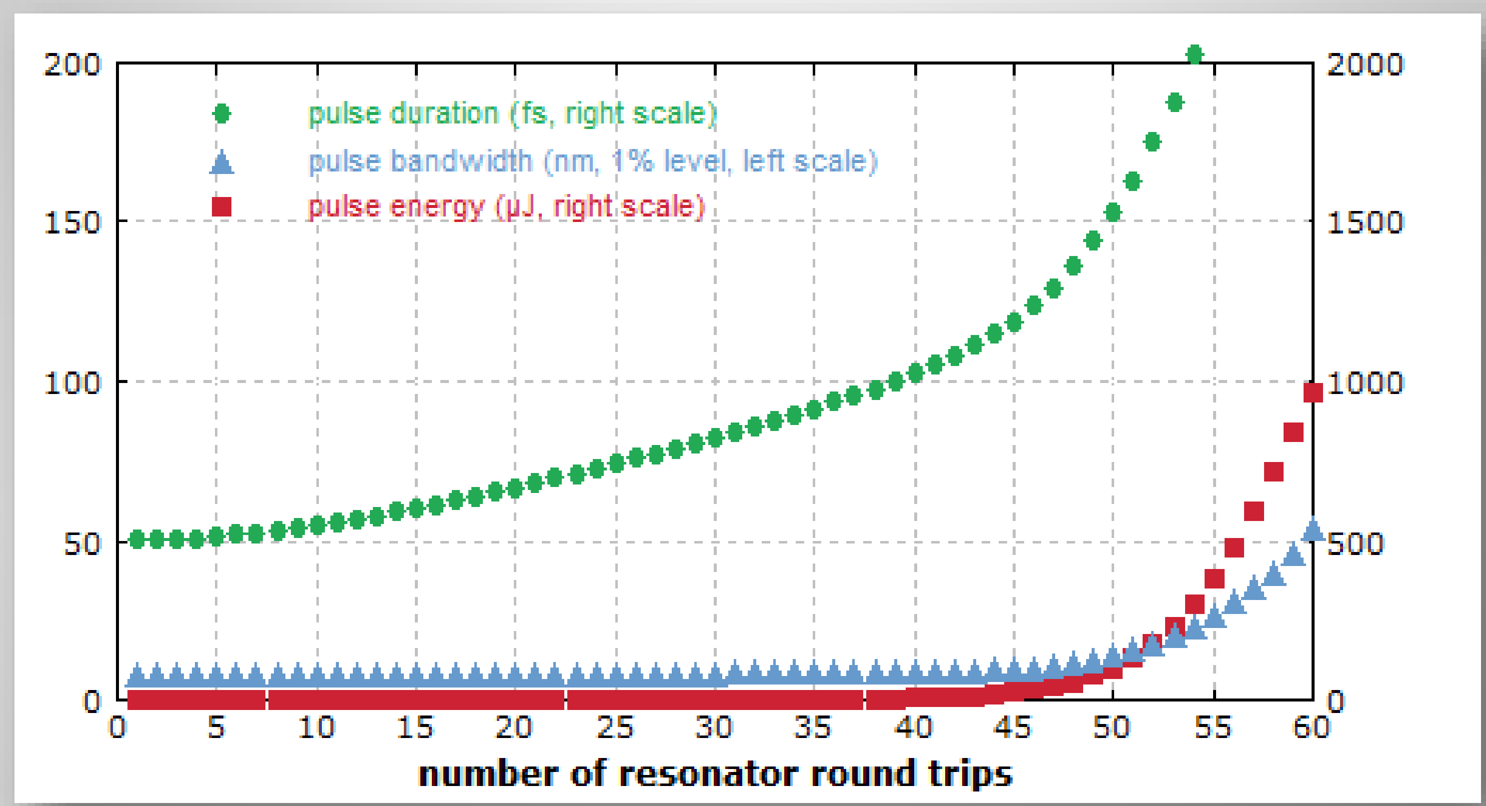
Example: higher-order soliton propagation:



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

Ultrashort Pulse Propagation (4)

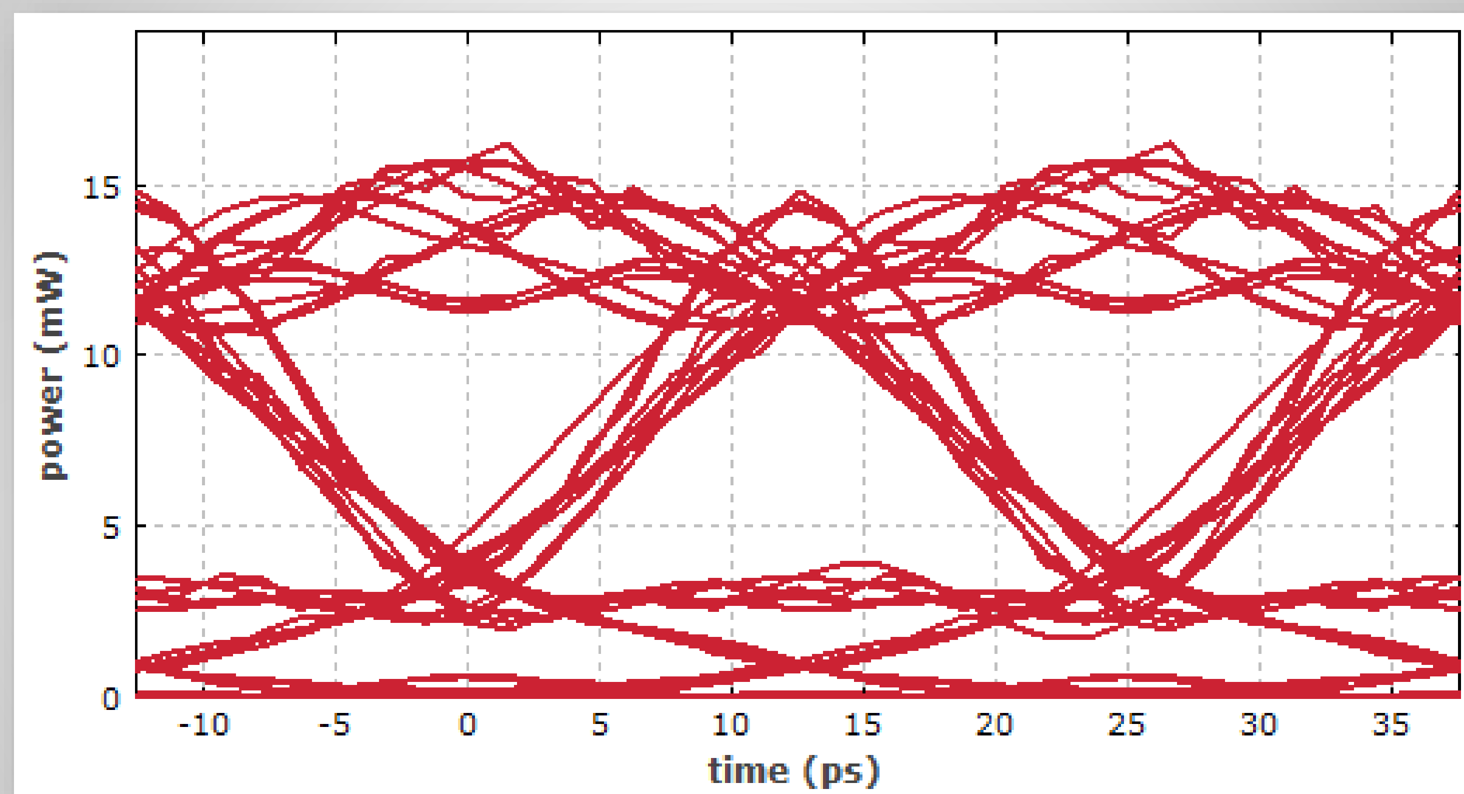
Example: regenerative bulk amplifier:



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

Ultrashort Pulse Propagation (5)

Example: optical data transmission in telecom fiber:



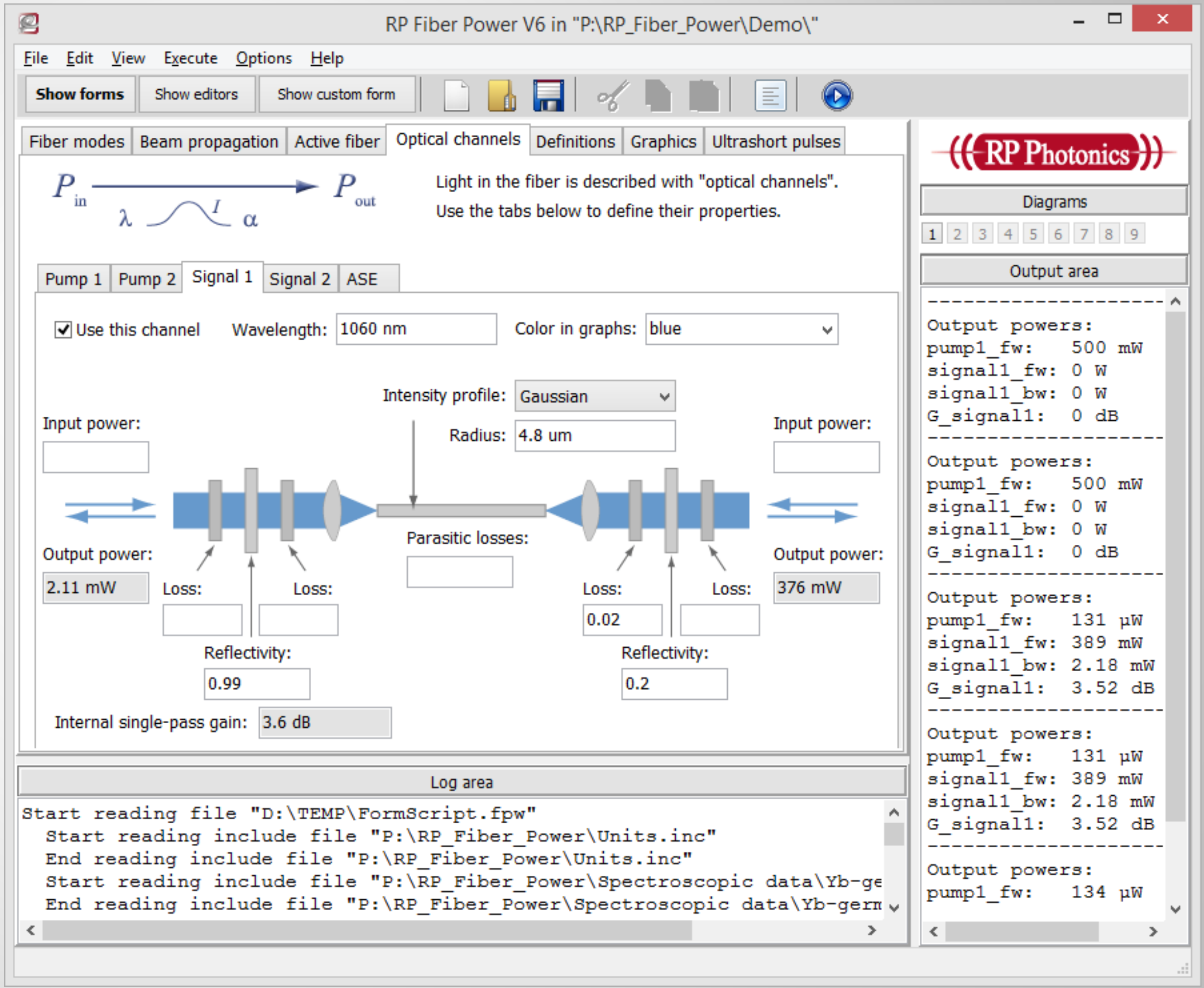
(Eye diagram generated with pseudorandom bit sequence.)

The User Interface (1)

Interactive Forms: simply enter the relevant data:

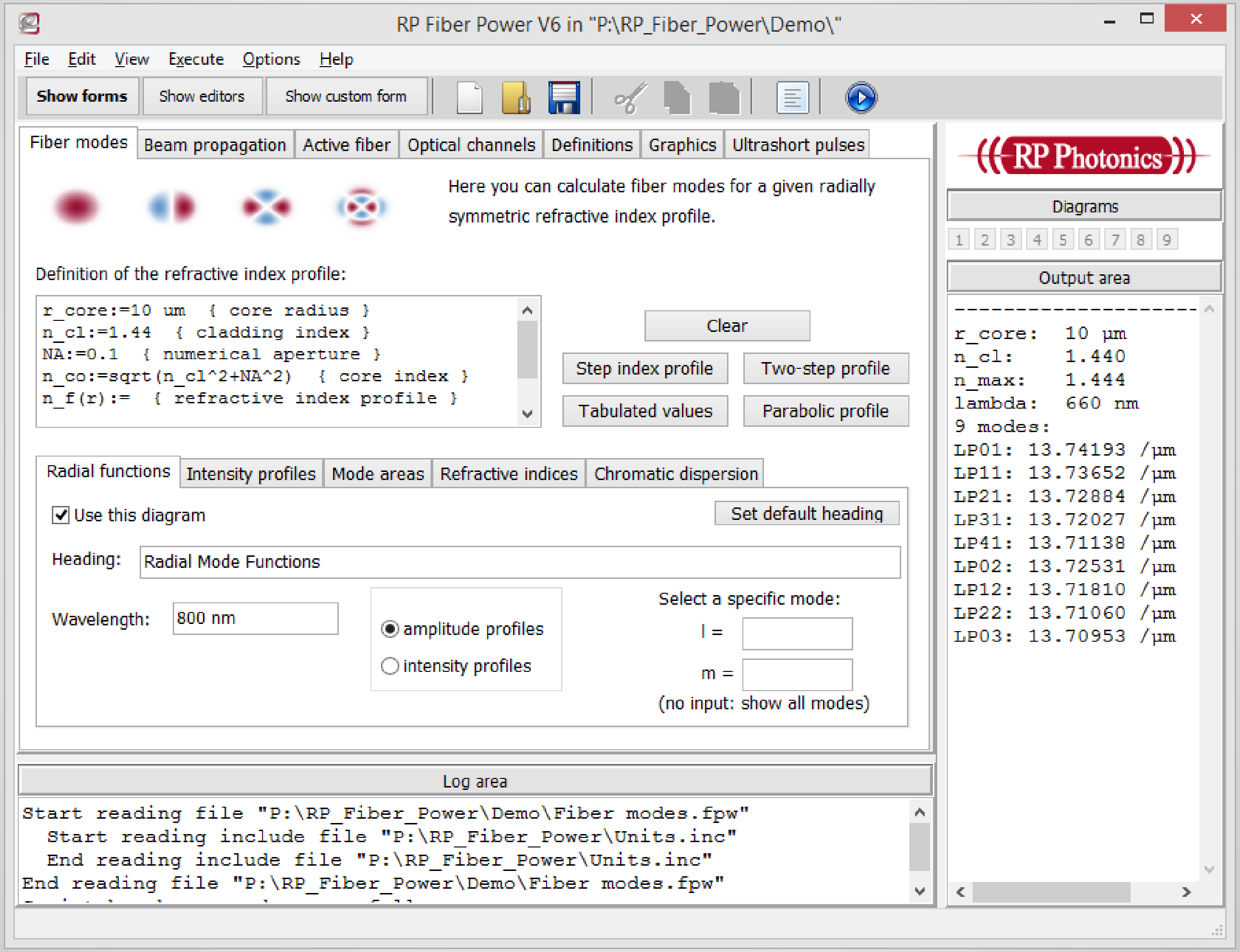
- fiber details
- optical channels (pump, signal, ASE)
- details of graphical output

Then execute this with one click to see your graphical and numerical output.



The User Interface (2)

Same for the mode solver, active fiber data, pulses, etc.



The User Interface (3)

Custom forms: get any tailored forms you need!

- Basic idea: such forms are similar to the standard forms, but they are not hard-coded: they are **defined in scripts** (text files), **which you can freely modify according to your needs!**
- The software comes with lots of those custom forms. You can modify each one as you like, and create complete new forms and calculations. Alternatively, **get them made** within the technical support.
- **They are very easy to use:** just fill out the input fields and execute to see the output values as well as created graphical diagrams.
- Ideal combination of flexibility and ease of use!

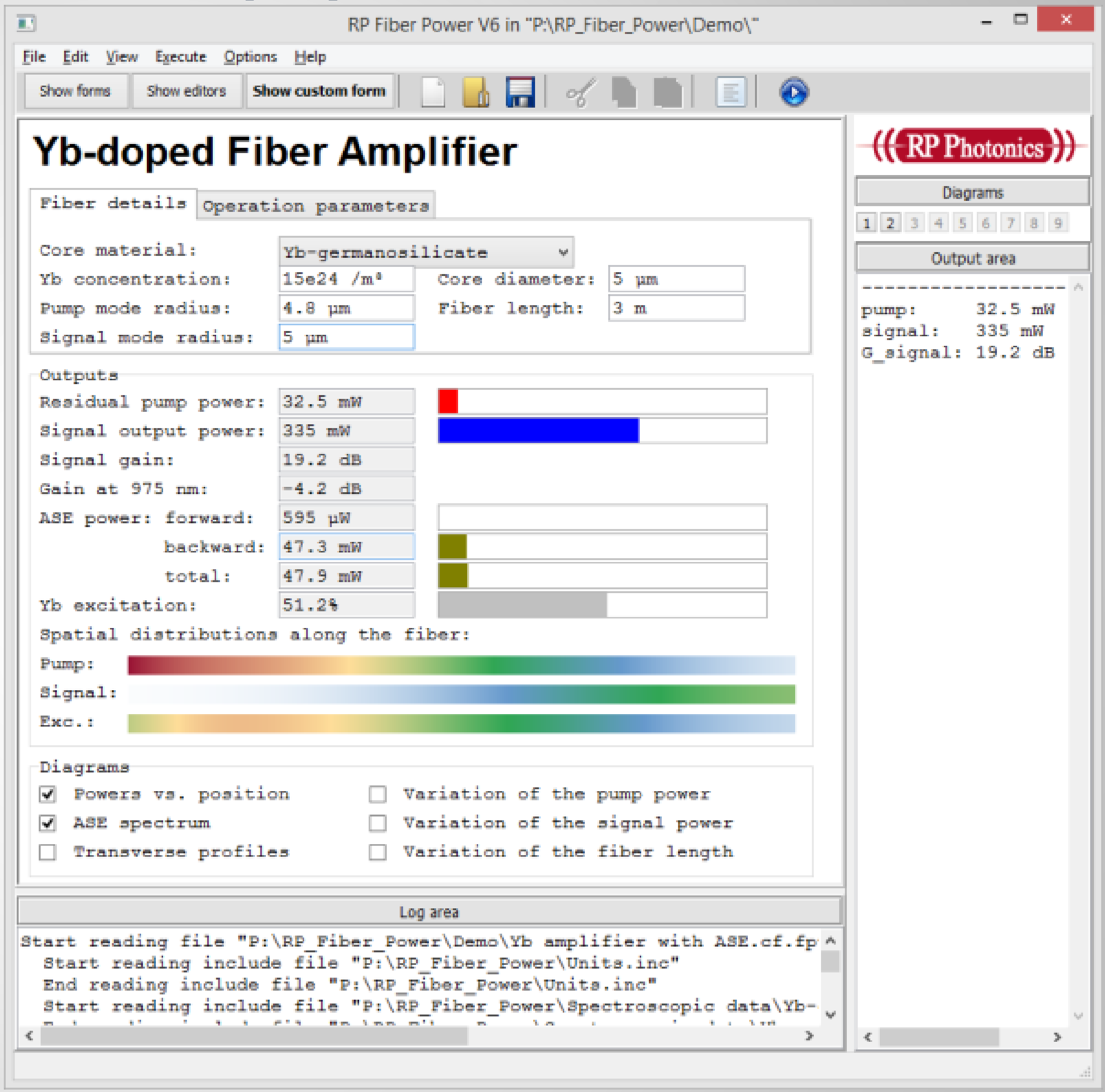
```
Custom form:
----------------------------------------------------------------------
$font: "Arial", bold, size = 20
Step-index Fiber
$image ((var r; r := if abs(y - 30 / 2) < 4 then 0.8 else 0.9; rgb(
$font: "Courier New", size = 11, space = 2.1
$box "Fiber details", size = (600, 0)
Core diameter:       ############   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"
```

The User Interface (4)

Simple example for custom forms:

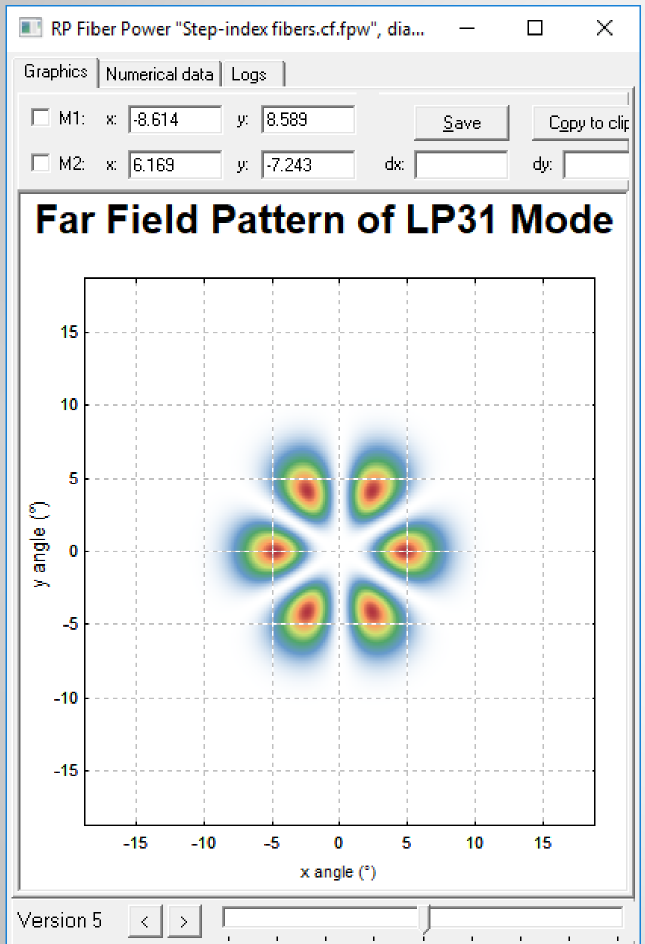
fiber laser model, calculating the spatial distribution of powers, output powers etc., also generating various plots

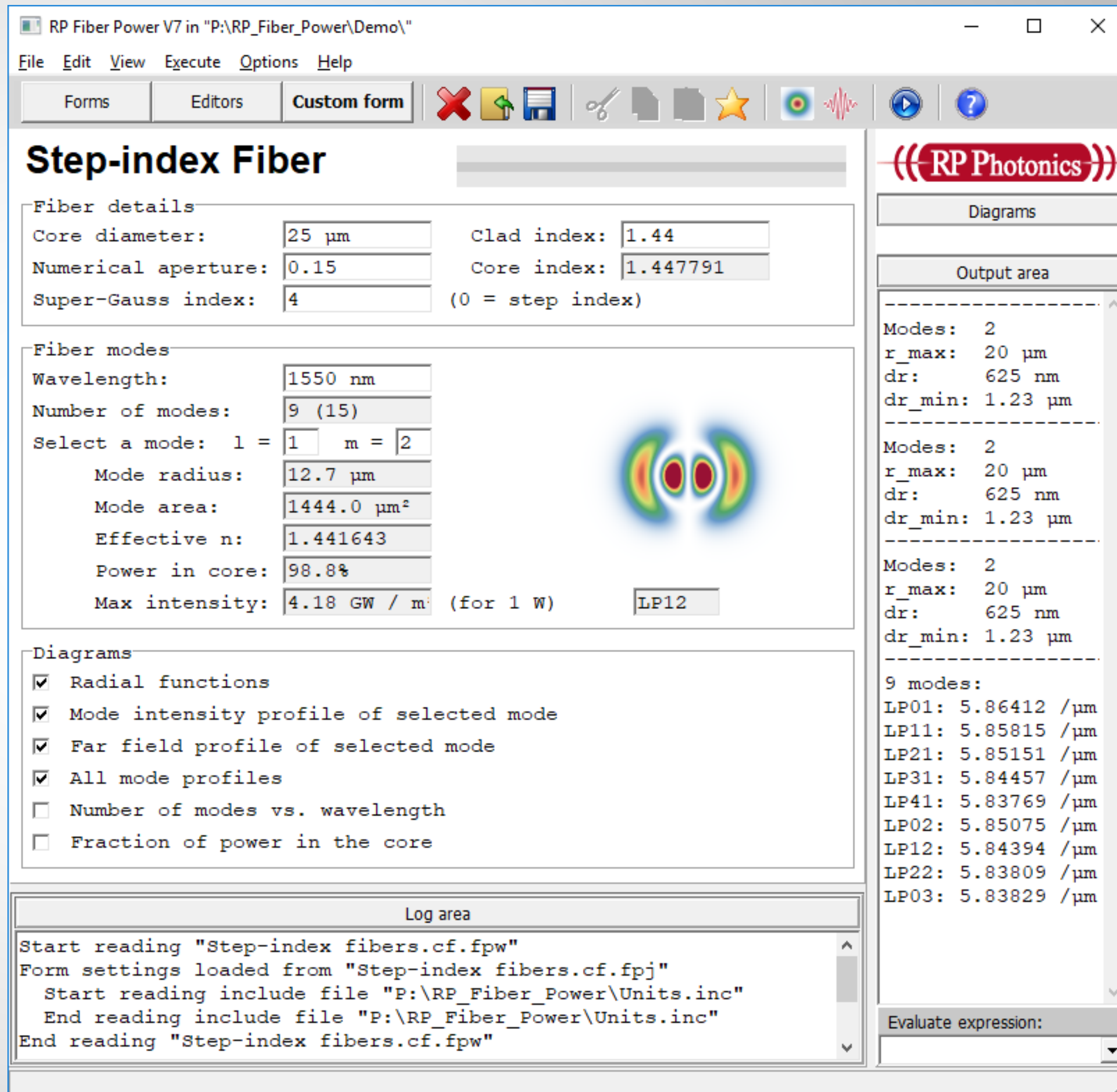
No problem if you need e.g. three signals instead of one – just modify the script!



The User Interface (5)

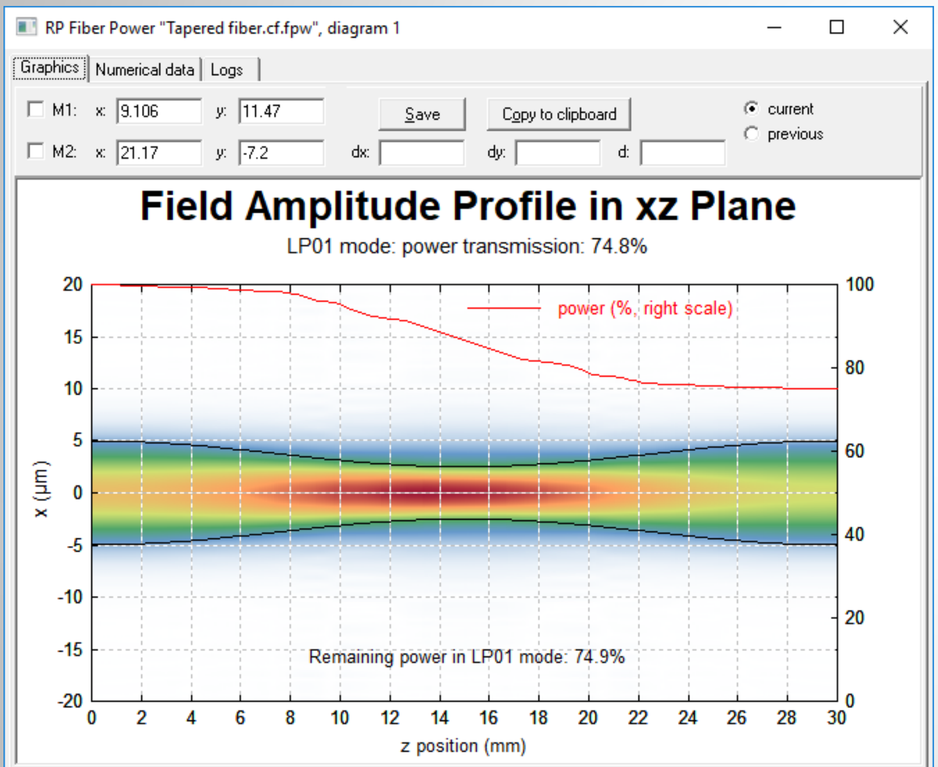
Another example: step-index fibers

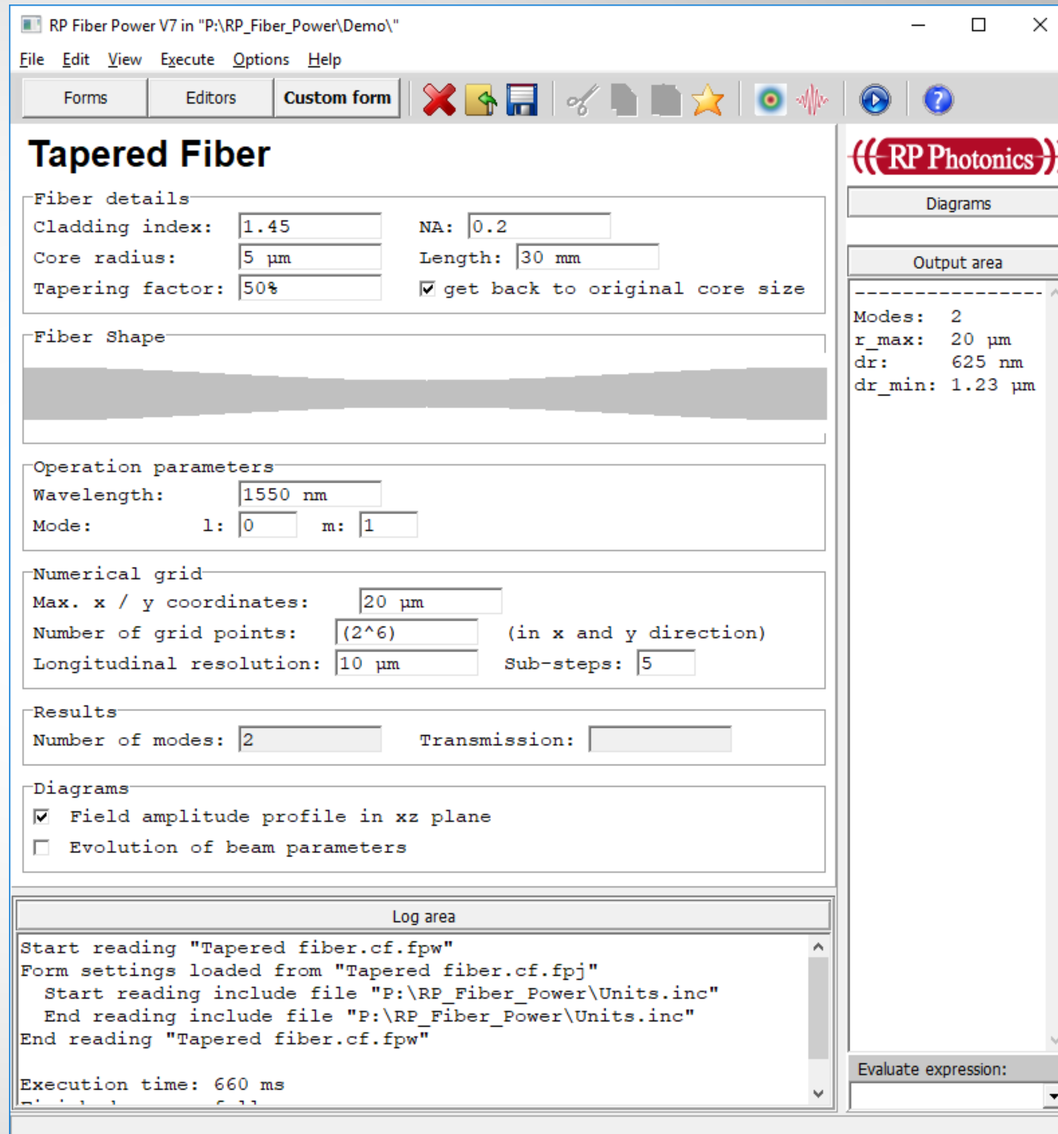




The User Interface (6)

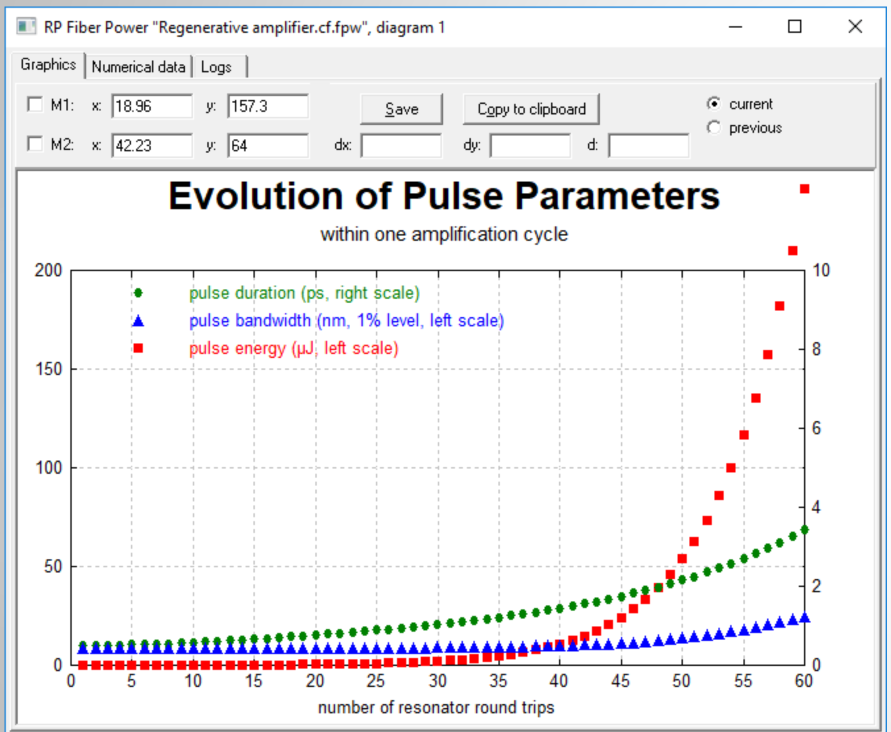
Another example: simulating light propagation in tapered fibers

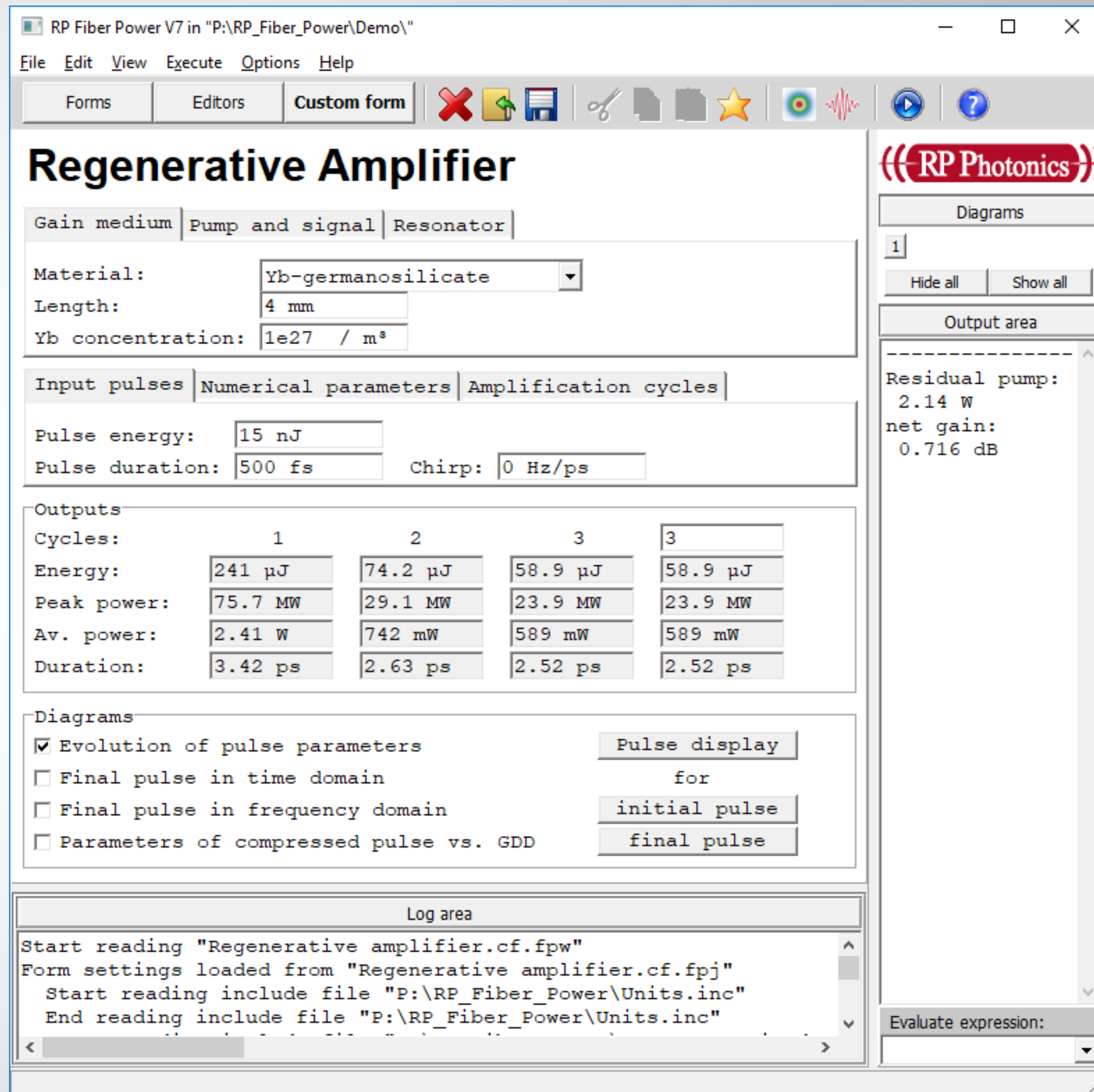




The User Interface (7)

Another example: regenerative amplifier





The User Interface (8)

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 (9)

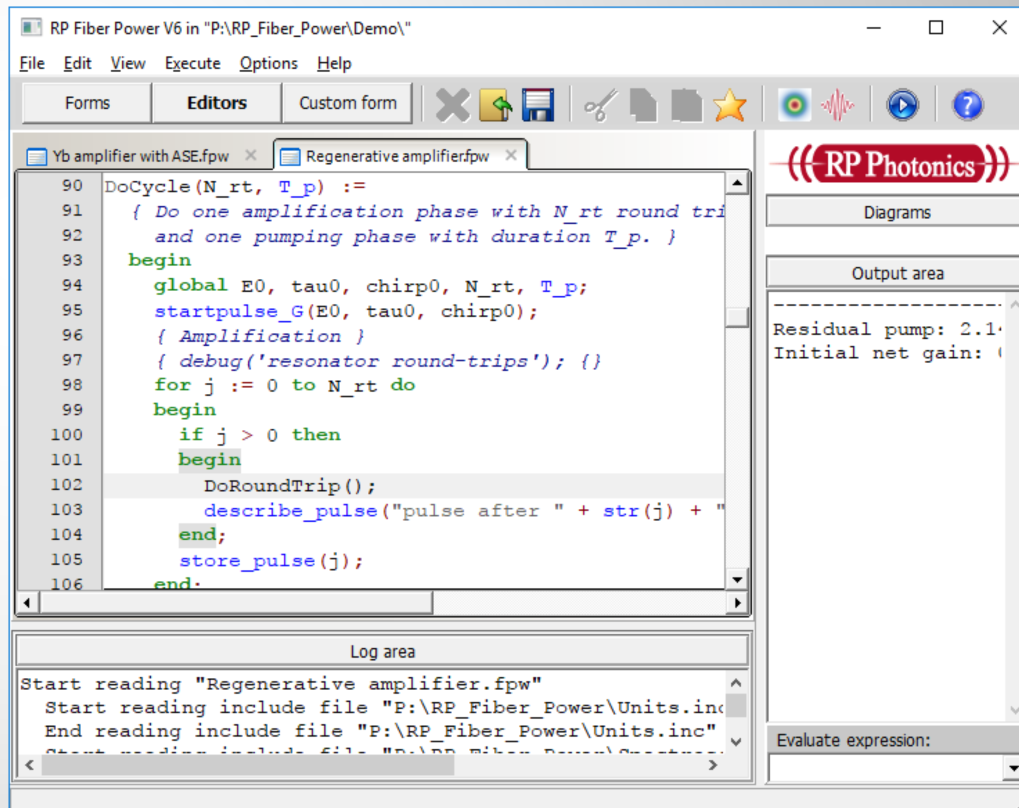
Where to get a script from?

- 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.
- Get help within the technical support – get even complete scripts developed for you!
- If you execute a calculation from the standard forms, a script based on your form inputs is automatically generated! Take it as a starting point for your own script.

The User Interface (10)

Powerful script editors and editing tools:

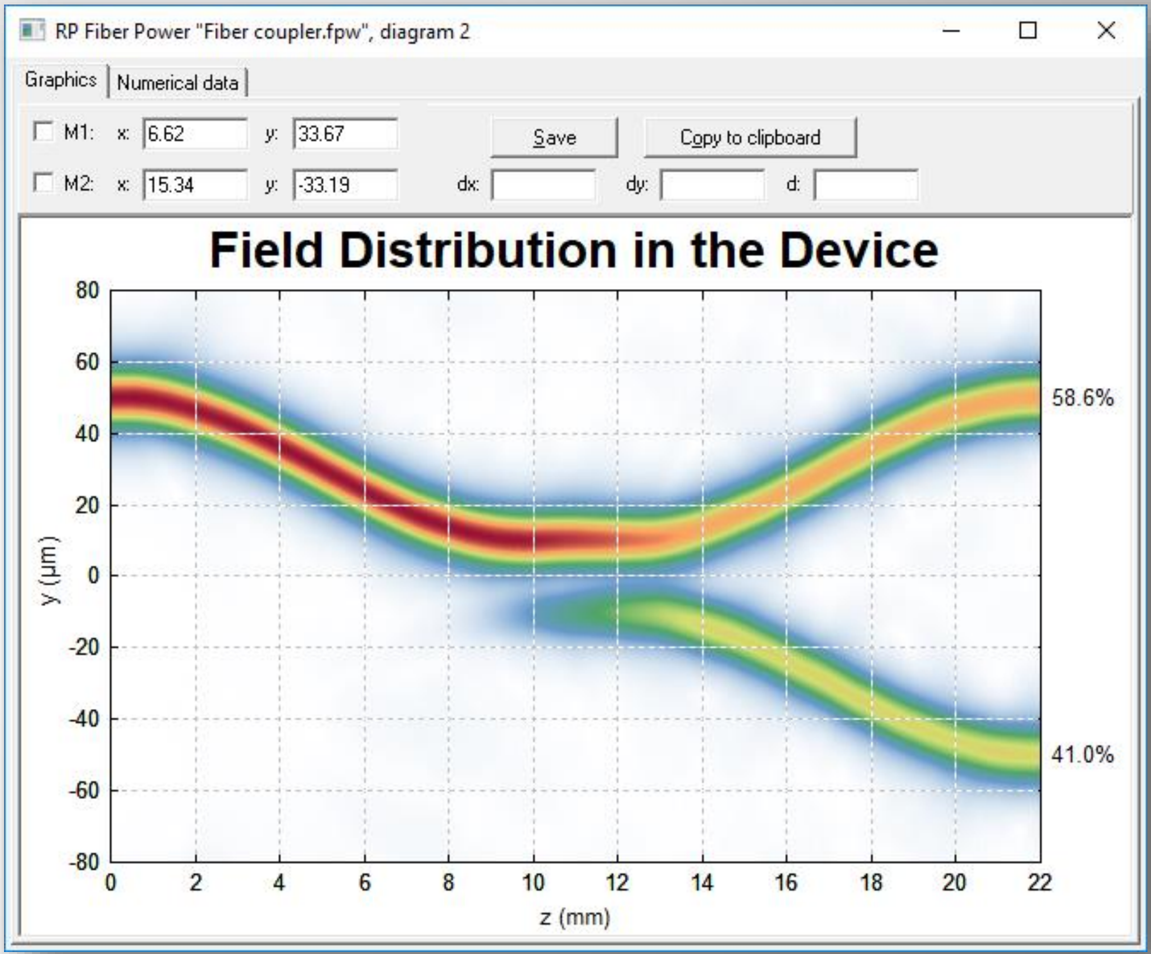
- **Code snippet library** for inserting frequently used parts of code
- **Parameter hints** for hundreds of functions
- **Multilevel undo/redo functionality**
- **Syntax highlighting** for good readability of code
- **Integrated syntax checker**
- Conveniently modify indentation of code blocks
- **Automatic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



The User Interface (11)

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



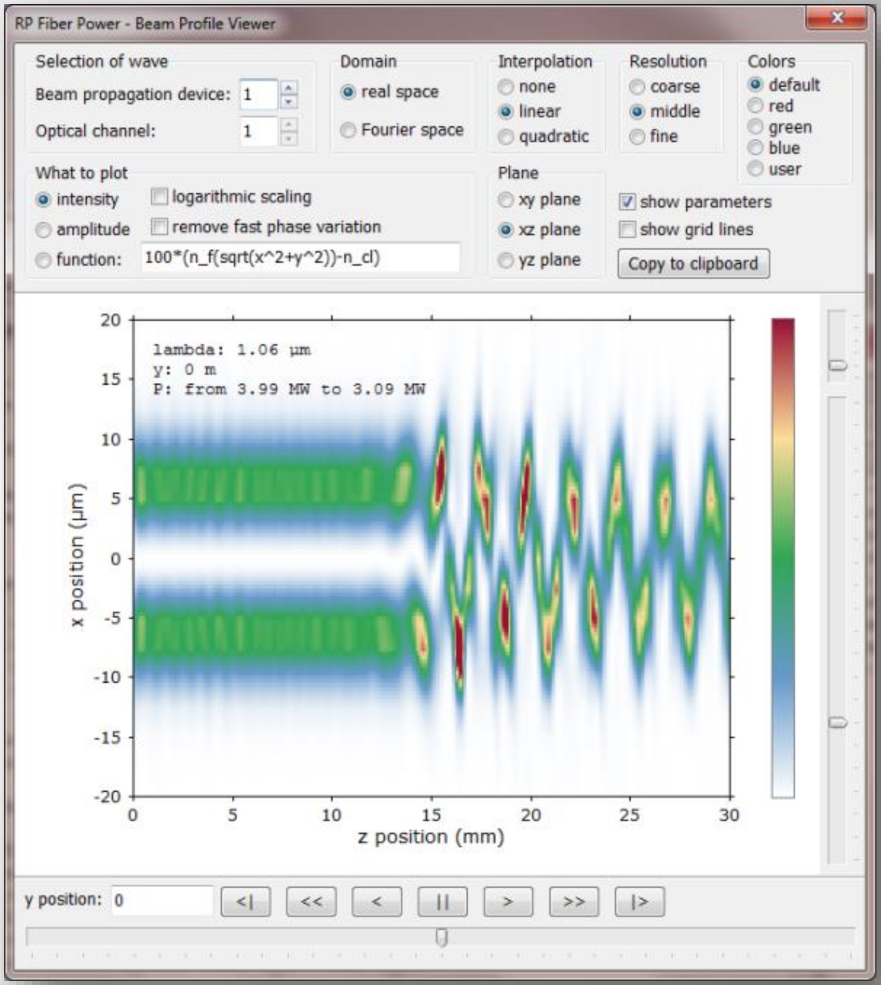
Also have flexible options for generating output in text form!

Put that into diagrams or files as you like.

The User Interface (12)

Interactive beam profile viewer

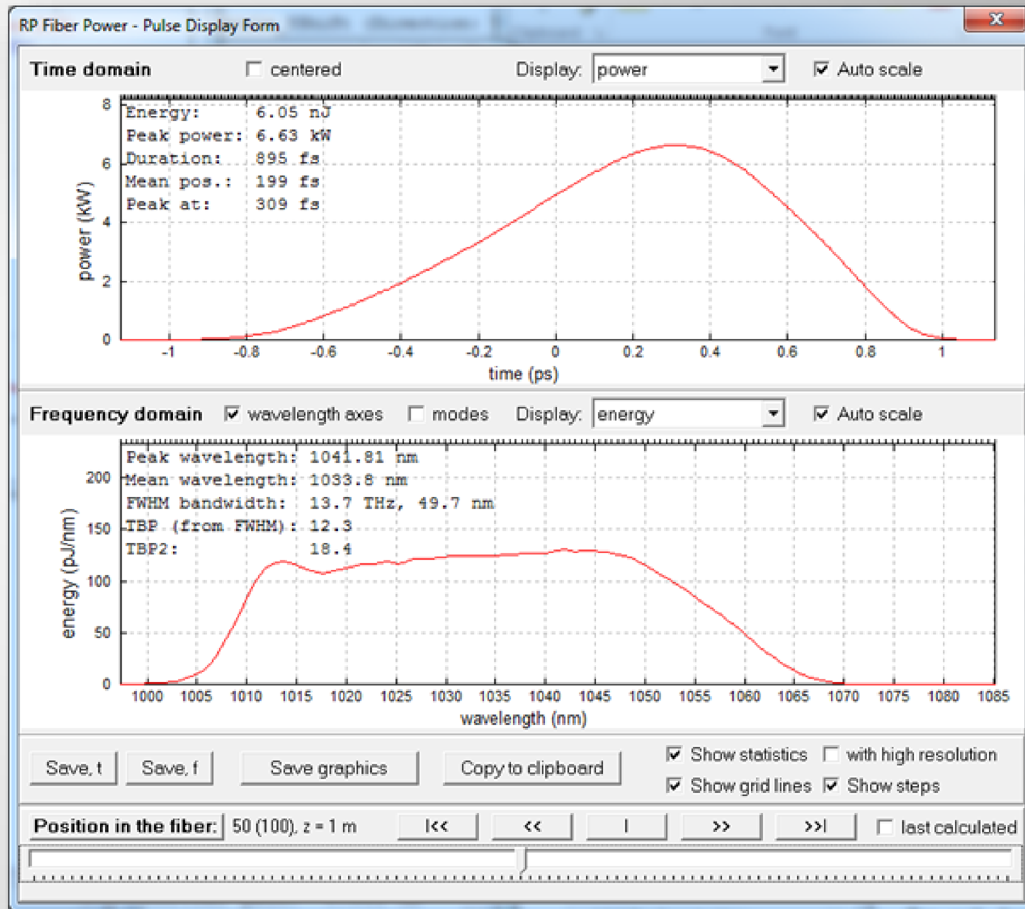
- Inspect calculated beam profiles.
- Switch between different wavelength components, displayed with different colors.
- Show profiles in xy, xz or yz plane.
- Change scaling or use logarithmic display in order to reveal weak satellites.
- Get parameters like center position and beam width displayed.



The User Interface (13)

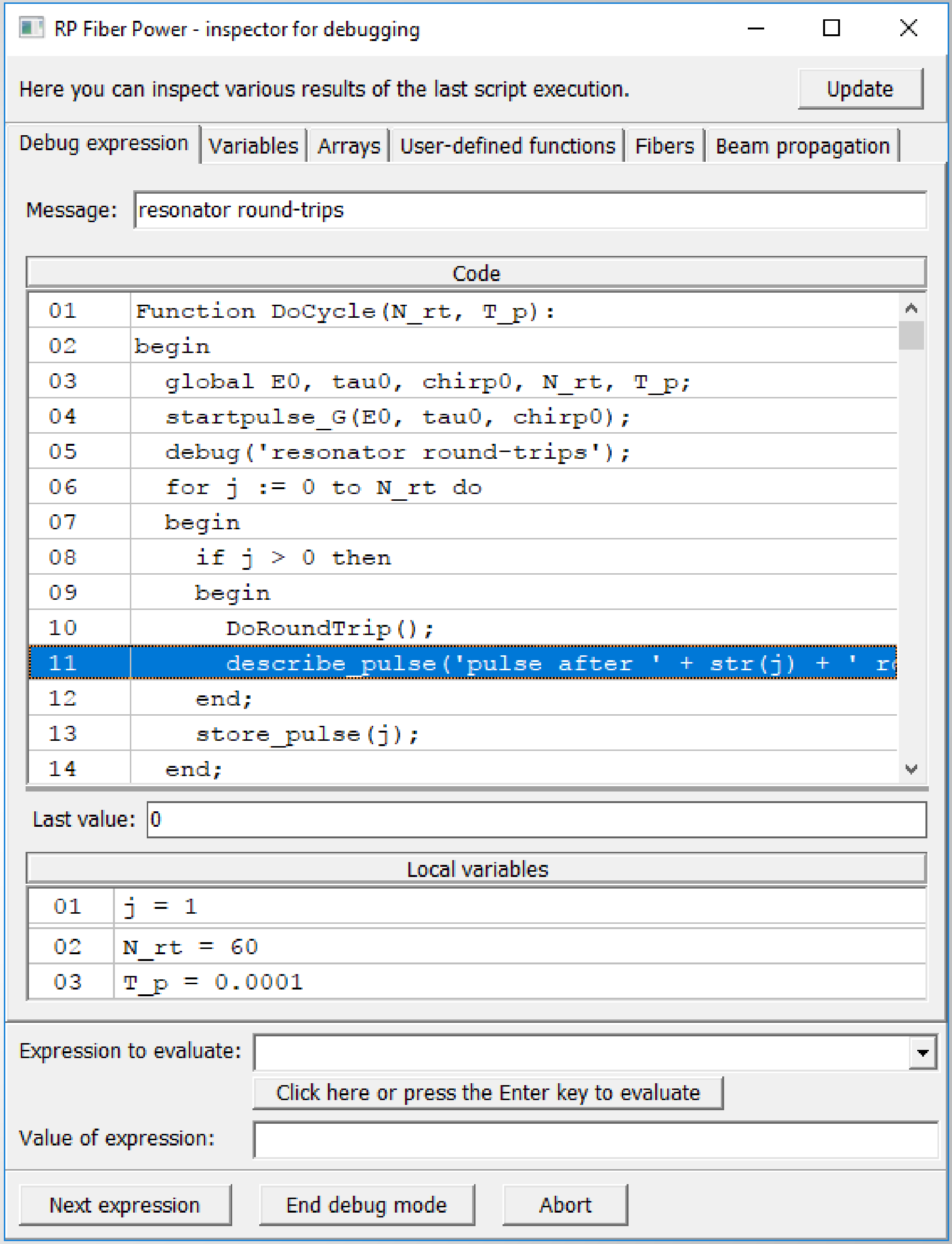
Interactive pulse display window

- 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.



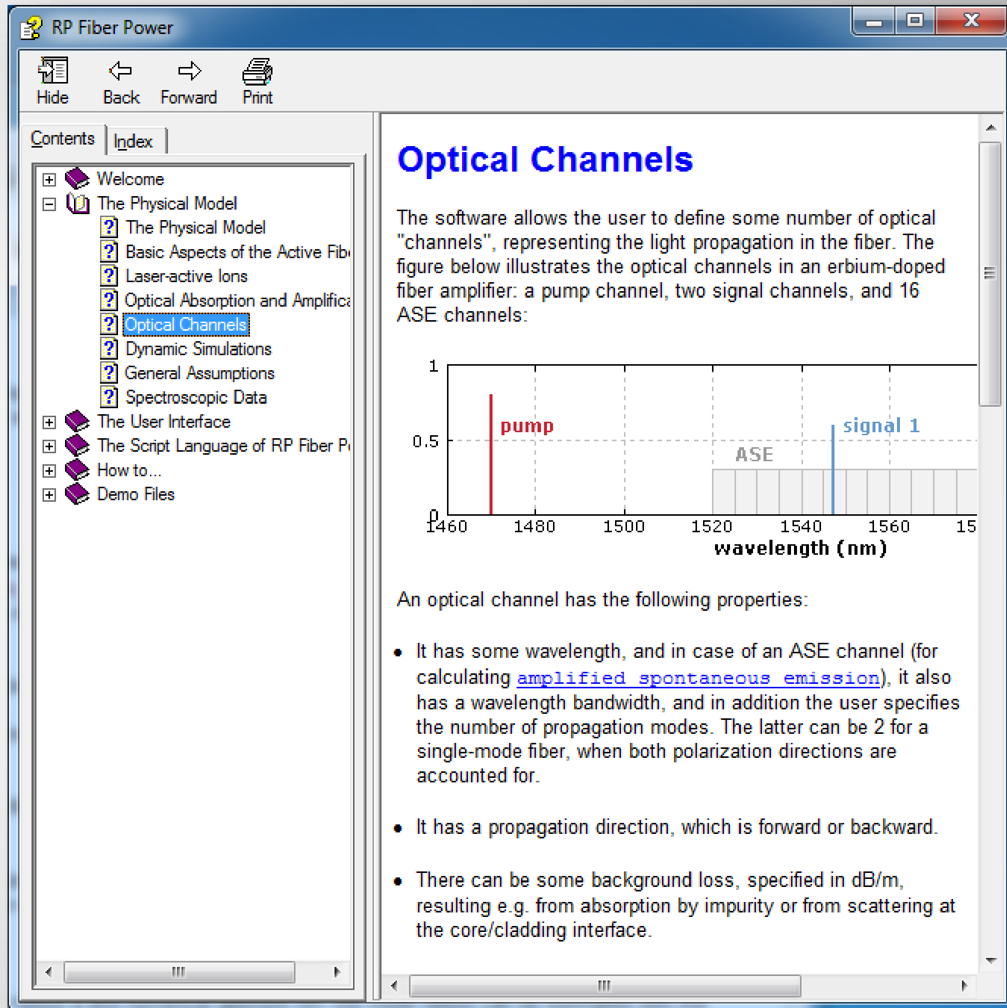
The Debugger

- 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 **online help system**
- comprehensive explanations of the used physical models, underlying assumptions, details of the script language, etc.
- dozens of **demo files**, demonstrating many different possibilities



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 himself, who is a distinguished expert in this area and has developed **RP Fiber Power**. He will make sure that you become another very satisfied user of the software!

Dr. Rüdiger Paschotta,
founder and managing director of RP Photonics,
developer of RP Fiber Power

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.,

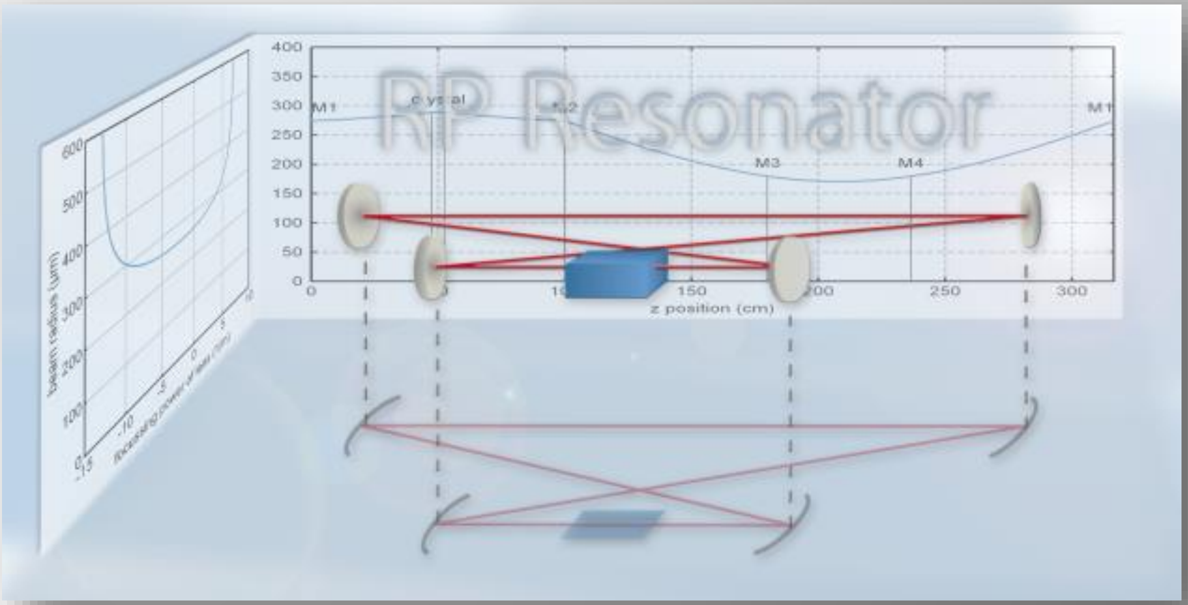
- to muddle through with insufficient tools?
- to use trial & error, wasting time and materials?
- to let customers wait while my competitors sell their products?

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:

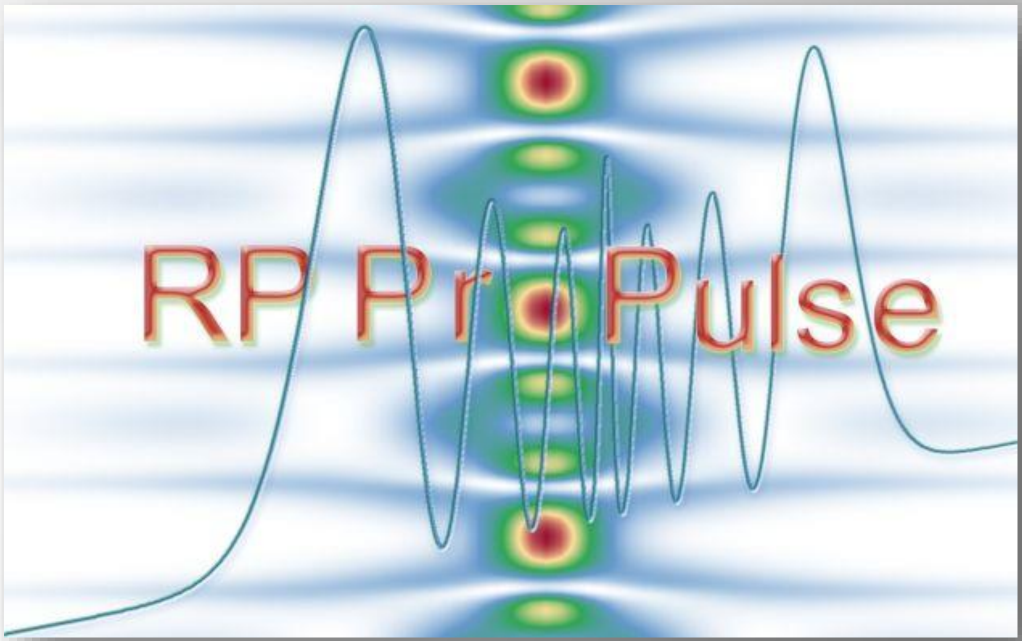
- design of optical resonators for lasers, OPOs, filters, etc.
- can fully parameterize the designs
- powerful script language for an enormous flexibility
- can do most sophisticated analysis and optimizations



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

Other Software from RP Photonics

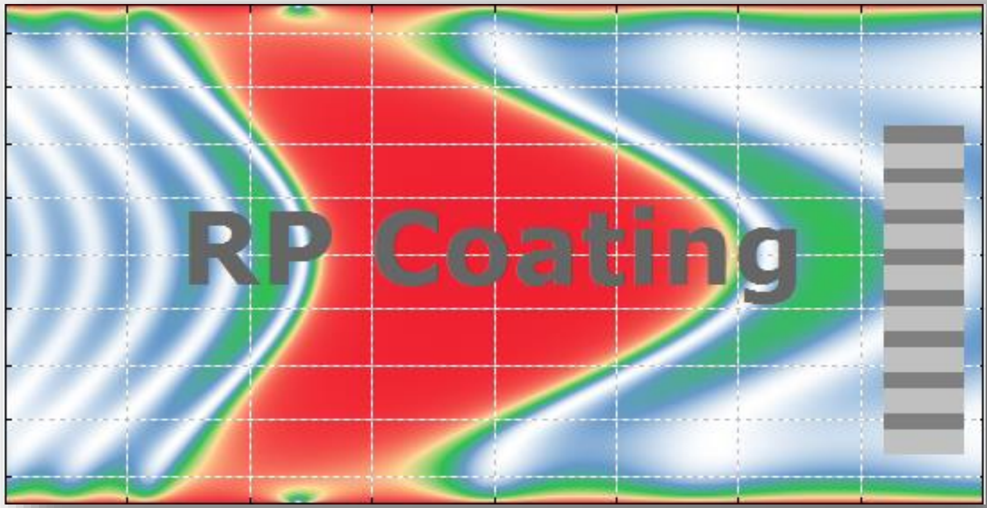
RP ProPulse:



- 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/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/coating.html