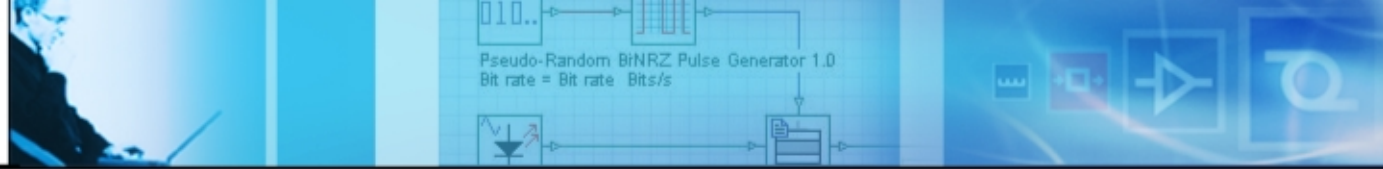
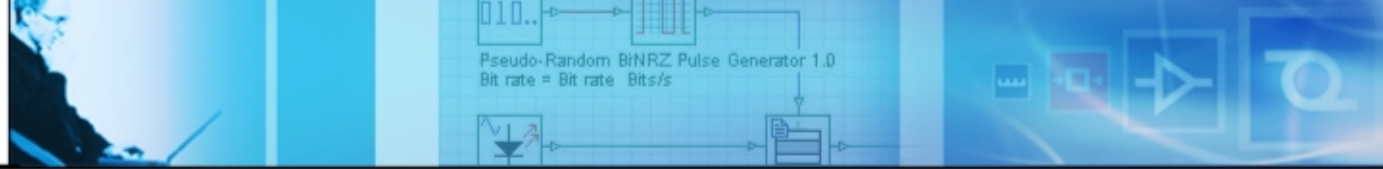


# Introduction to Optical Amplifiers: Simulation, Automated Design and Analysis



# Outline

- Types of Optical Amplifiers
- Typical configurations
- OptiAmplifier
- Designing Optical Amplifiers



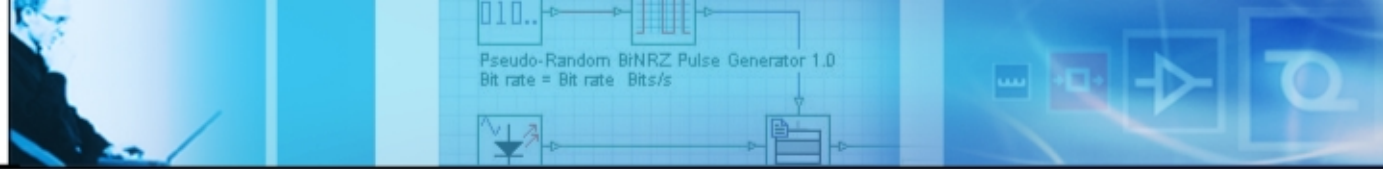
# Types of Optical Amplifiers

- Semiconductor Optical Amplifiers (SOAs)
- Erbium Doped Fiber Amplifiers (EDFAs)
- Raman Amplifiers
- Hybrid Amplifiers



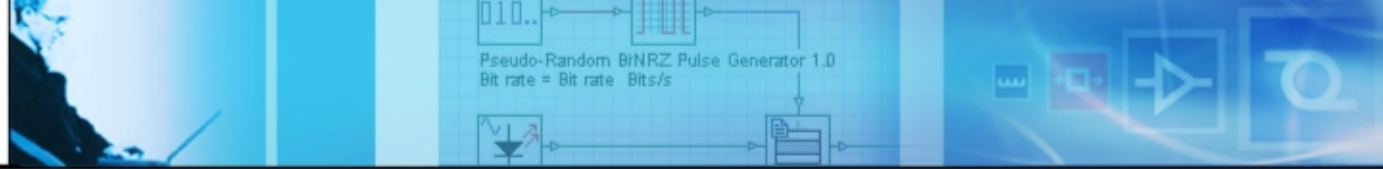
# Types of Optical Amplifiers

- In the early 1980s, attention was focused on Raman fiber amplifiers (RFA's) and semiconductor optical amplifiers (SOA's)
- The RFA is based on the nonlinear effect of stimulated Raman scattering - undoped glass fiber core represents the gain medium
- In the mid-1980s, a group led by D.N. Payne at the University of Southampton developed a technology of rare earth ions deposition in single-mode silica fibers and in 1987 the first EDFA was introduced



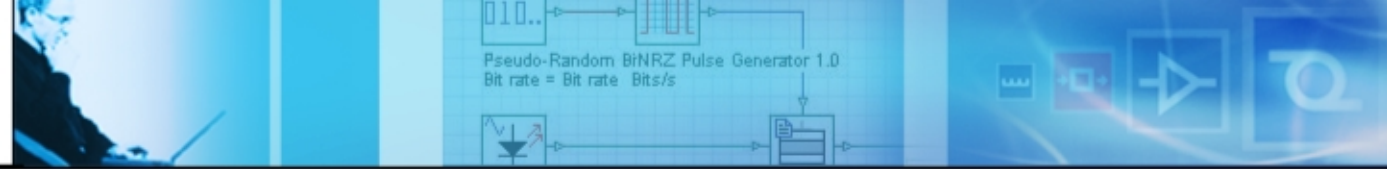
# Types of Optical Amplifiers

- The stimulated emission coefficient is proportional to pump power density in the core - to achieve reasonable gains with currently available pump LDs, fibers with either small core radius or large NA (not compatible with standard communication fibers) must be used .
- Gain of the SOA is polarization dependent, due to a short lifetime of charge carriers in semiconductors SOA suffer from large inter-modulation distortion and cross-talk.
- Optical amplifiers are bit rate transparent, can amplify signals at different wavelength simultaneously, in contrast to electronic regenerators they are insensitive to the type of signal modulation.



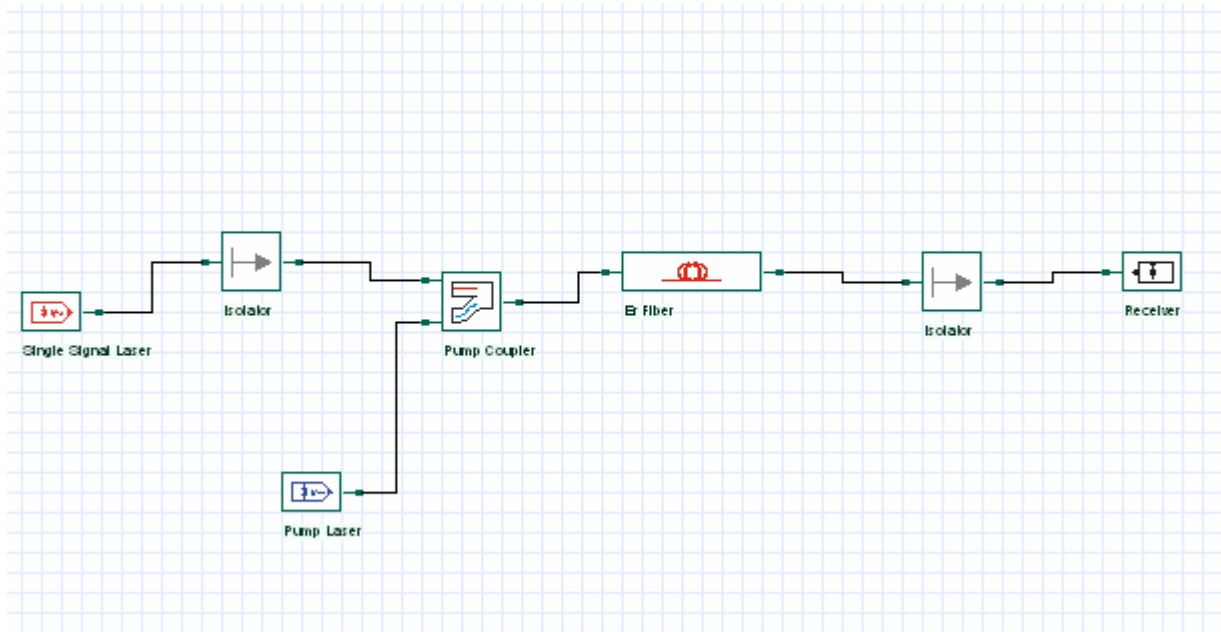
# Types of Optical Amplifiers

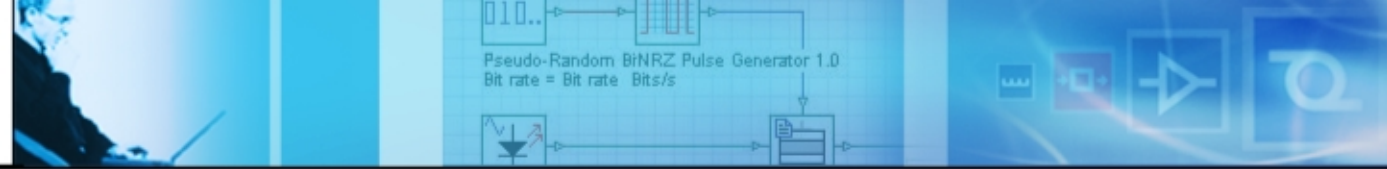
- SOAs find new applications as wavelength converters in WDM networks.
- With the progress in the manufacture of high-power pump lasers, along with the demand for amplification bandwidth, Raman amplification is playing an important role in WDM communications.
- Hybrid amplifiers: EDFA + Raman



# Typical Configurations

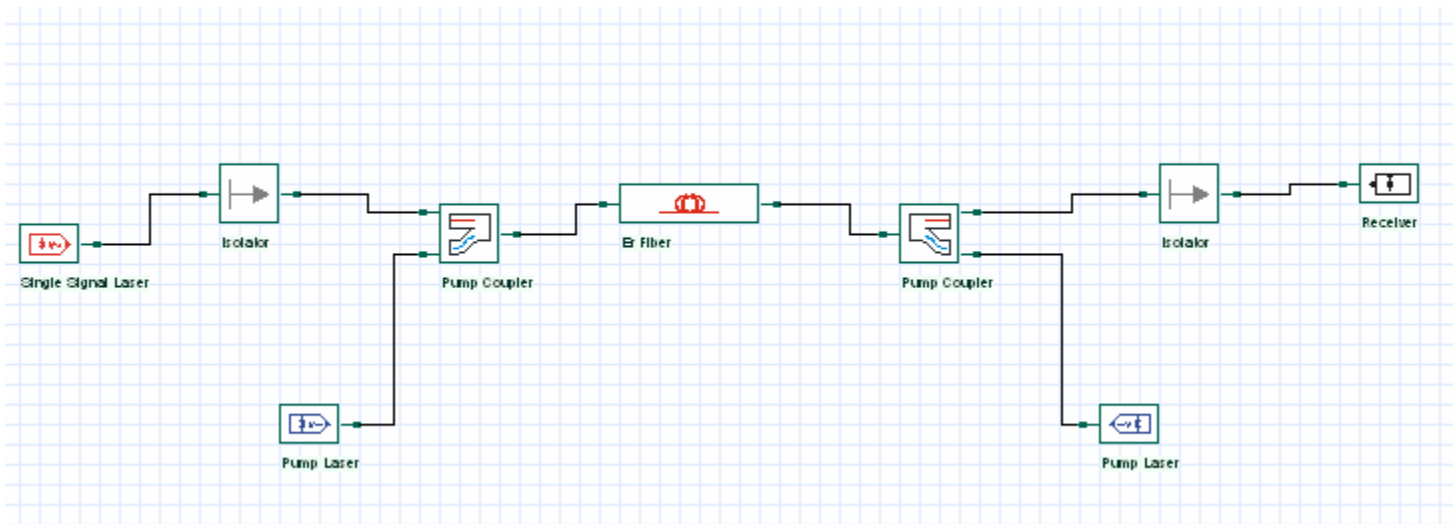
## Co-propagating pump





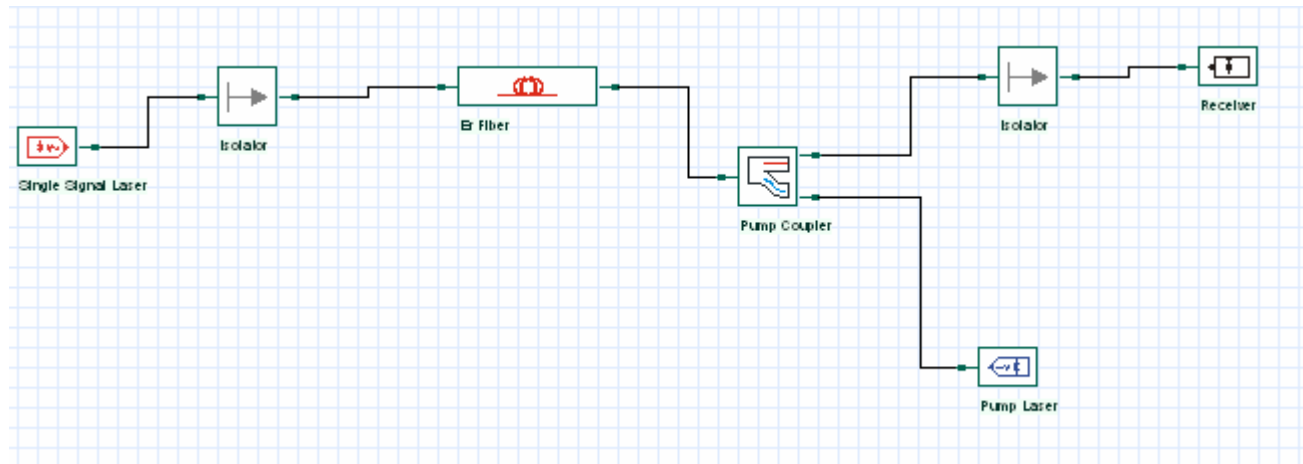
# Typical Configurations

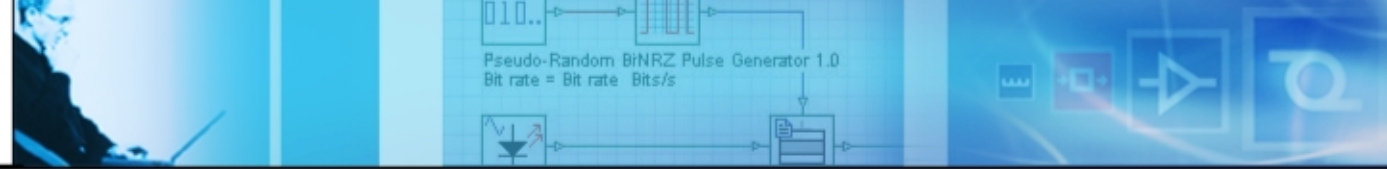
## Bi-directional pump



# Typical Configurations

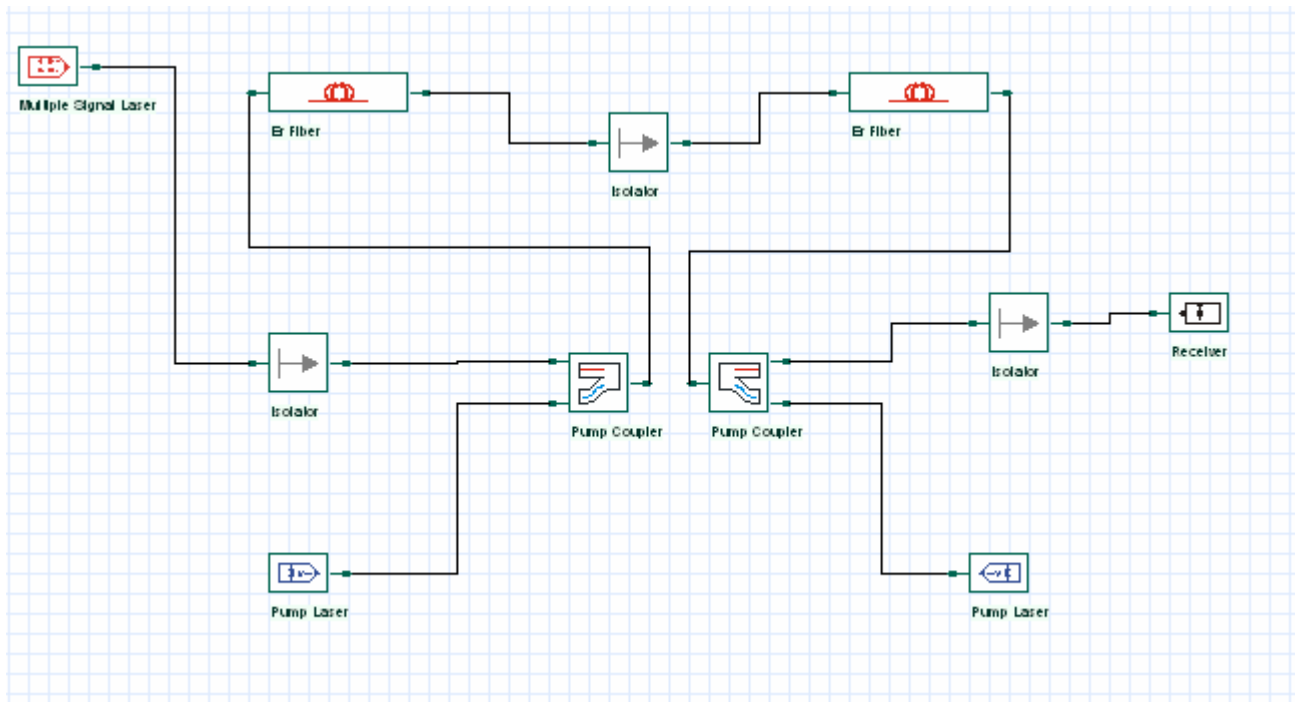
## Counter-propagating pump

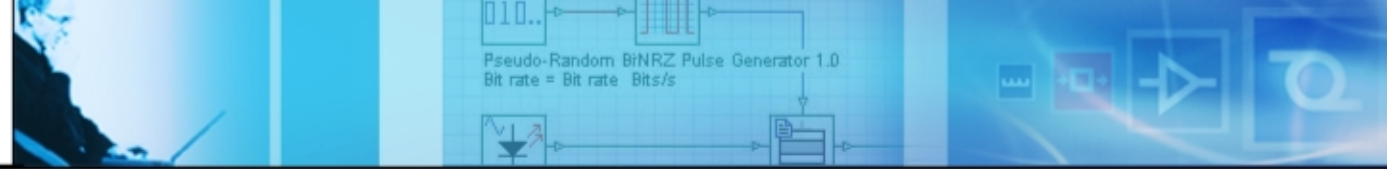




# Typical Configurations

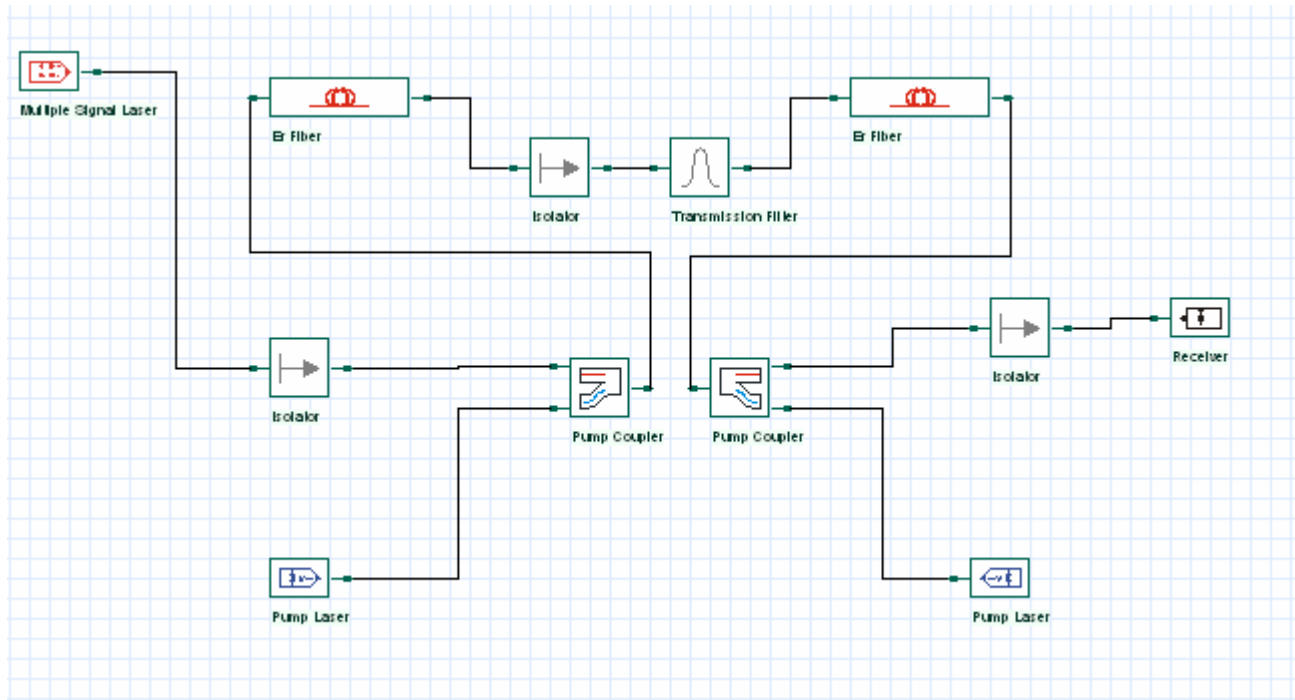
## Multi stage





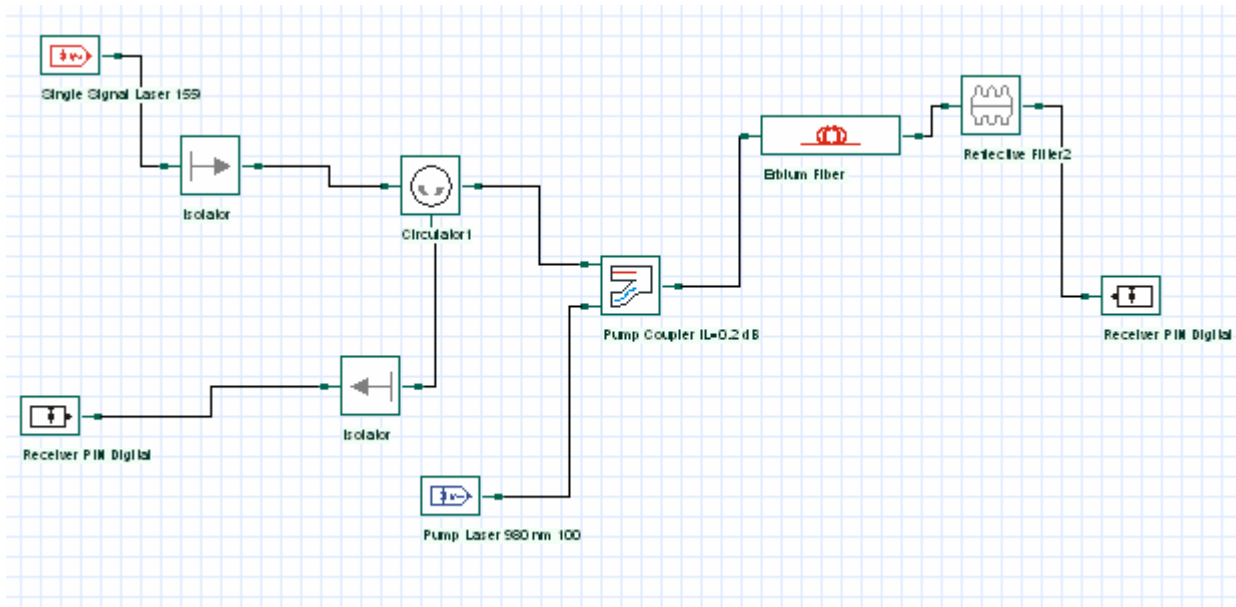
# Typical Configurations

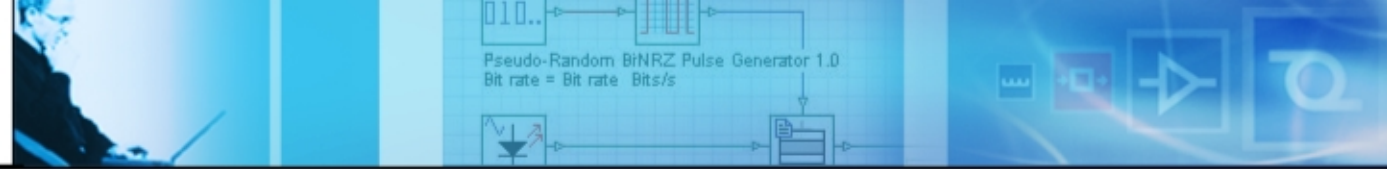
Multi stage gain flattened



# Typical Configurations

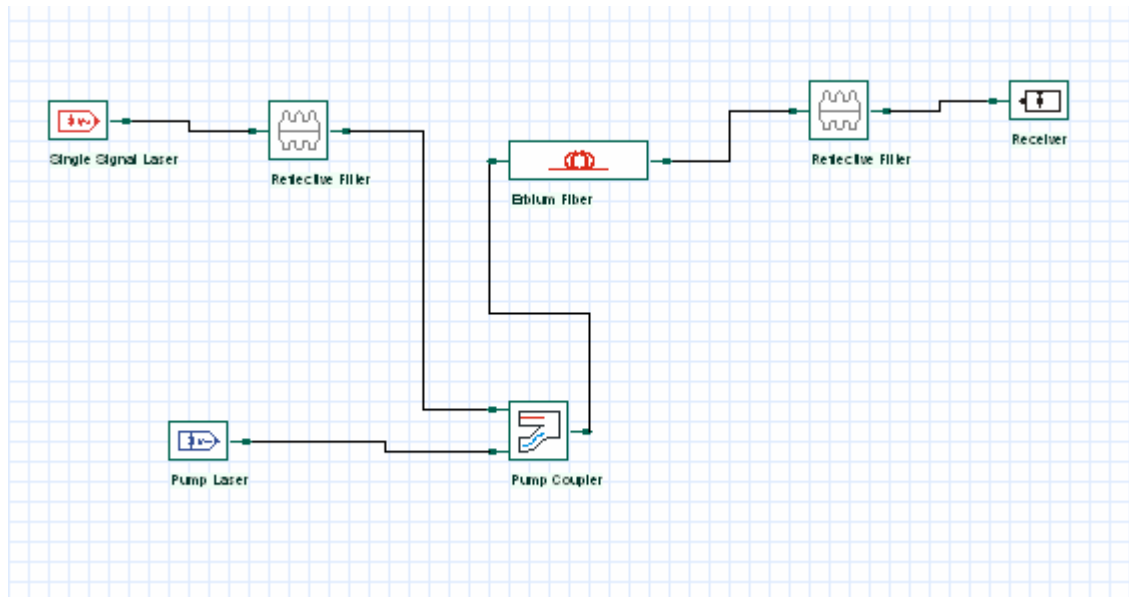
## Reflective amplifier

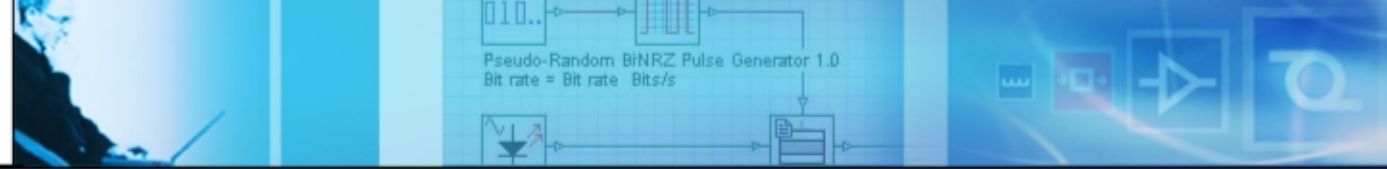




# Typical Configurations

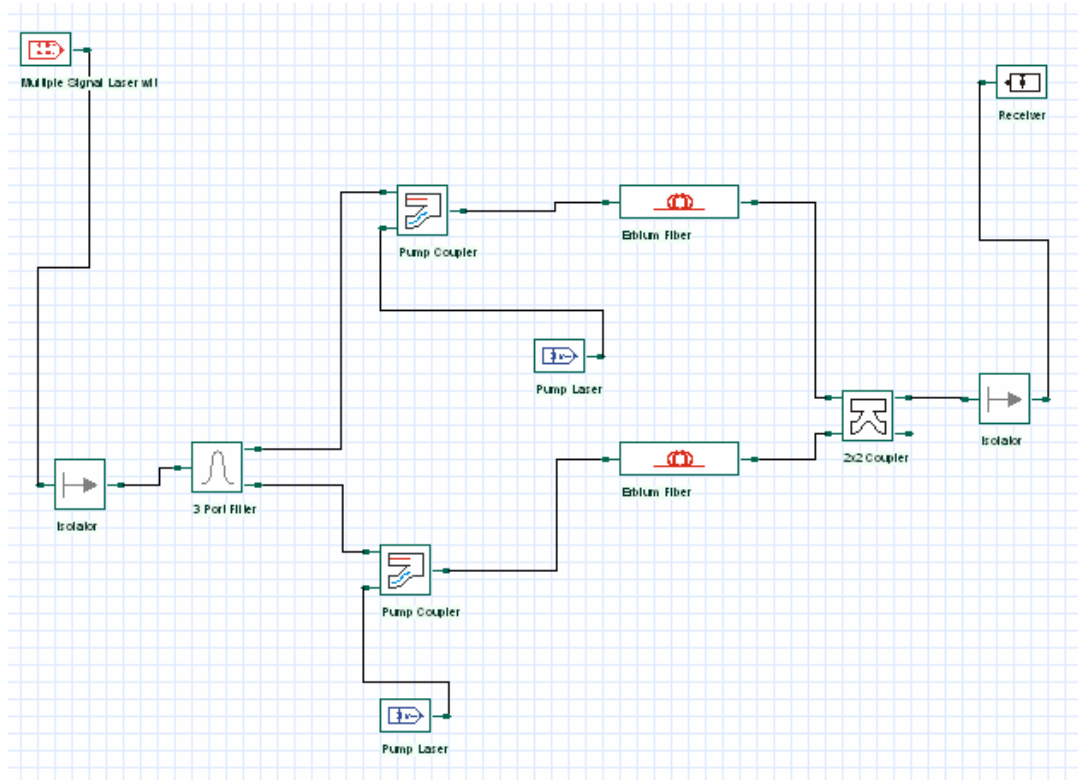
## Gain clamped





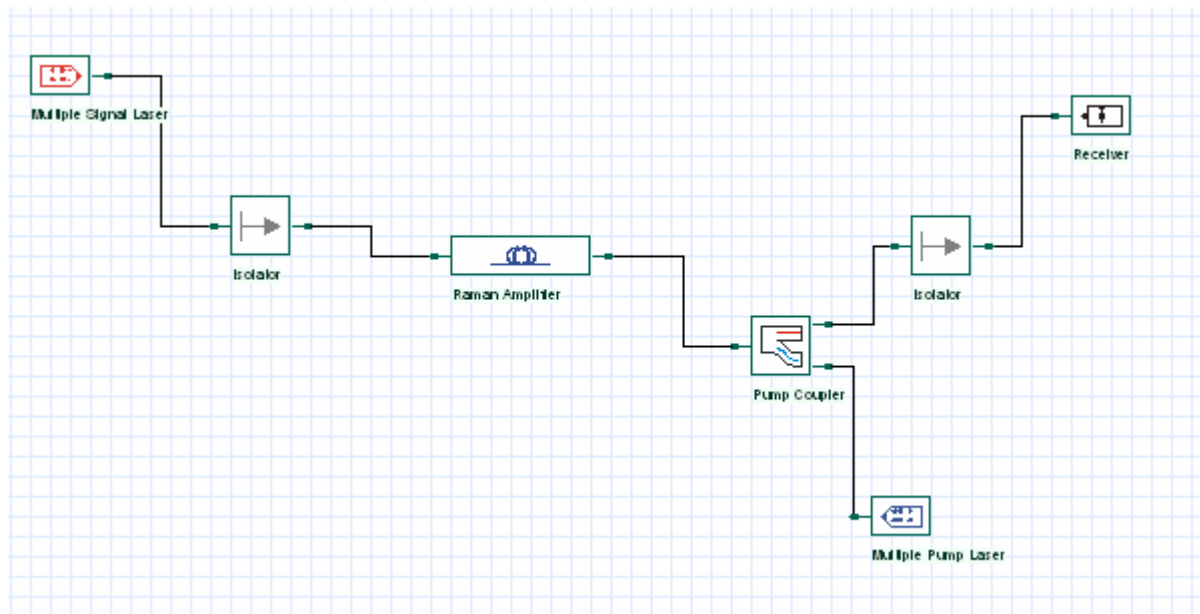
# Typical Configurations

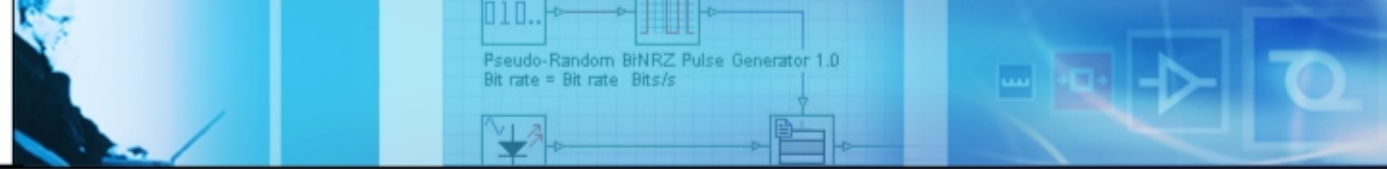
## Split band



# Typical Configurations

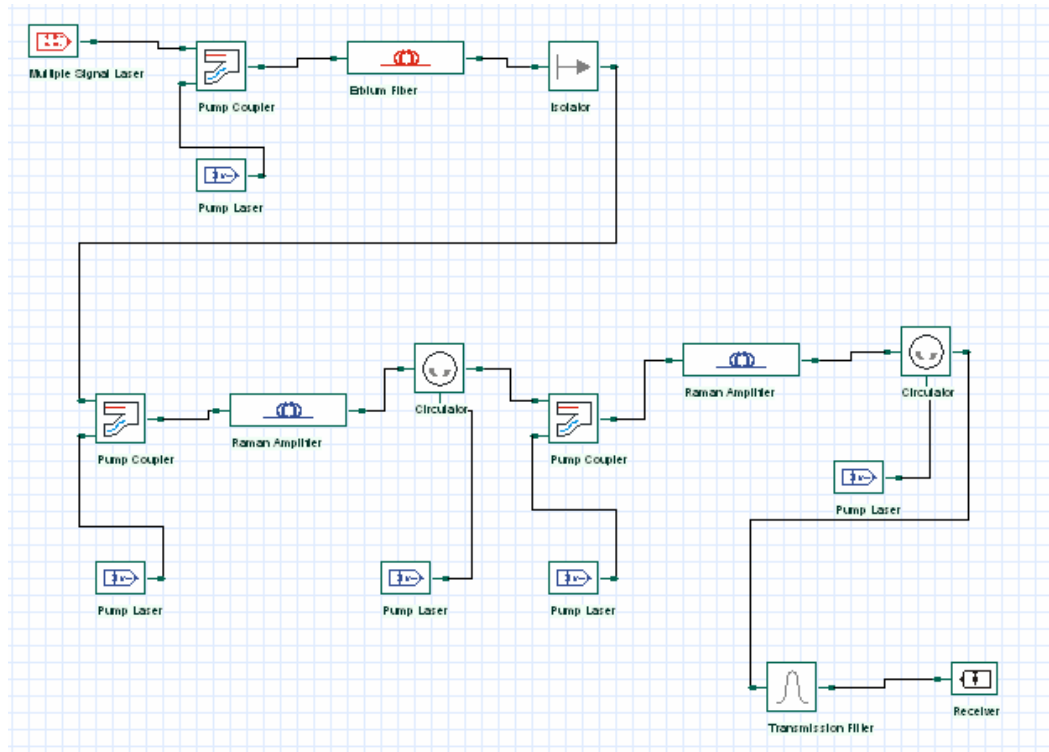
## Raman counter-propagating pump

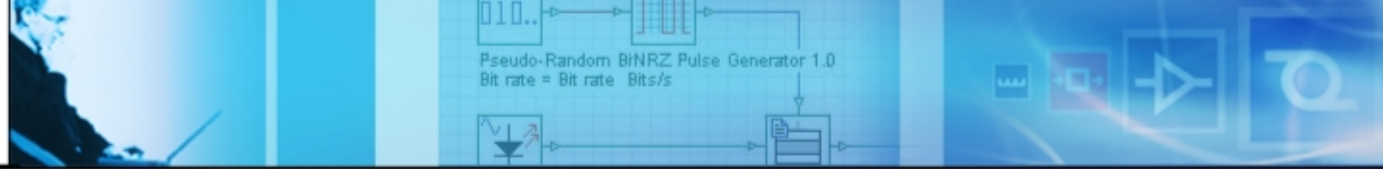




# Typical Configurations

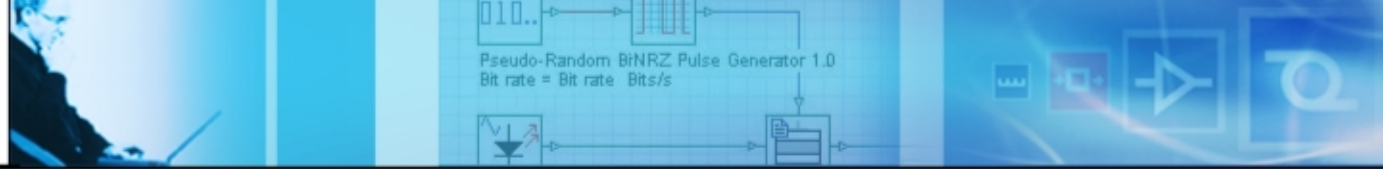
## Hybrid amplifier





# Designing Optical Amplifiers

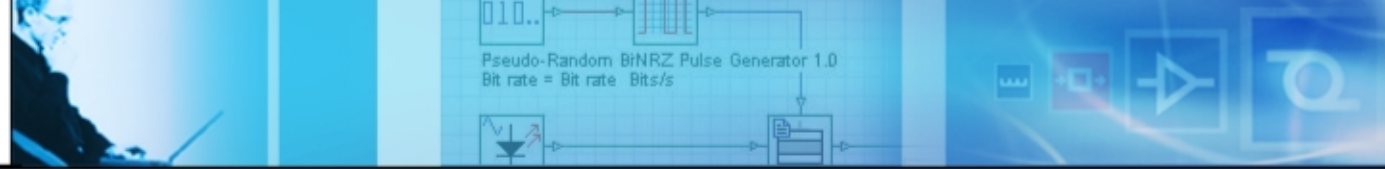
**Software can assist in determining the tradeoff between optical amplifiers cost and performance by calculating how metrics such as minimum output power, maximum noise figure, maximum gain ripple, and minimum pump power depend on device specifications such as pump wavelength range, passive component losses, and component costs.**



# OptiAmplifier

## Optical Fiber Amplifier and Laser Design Software

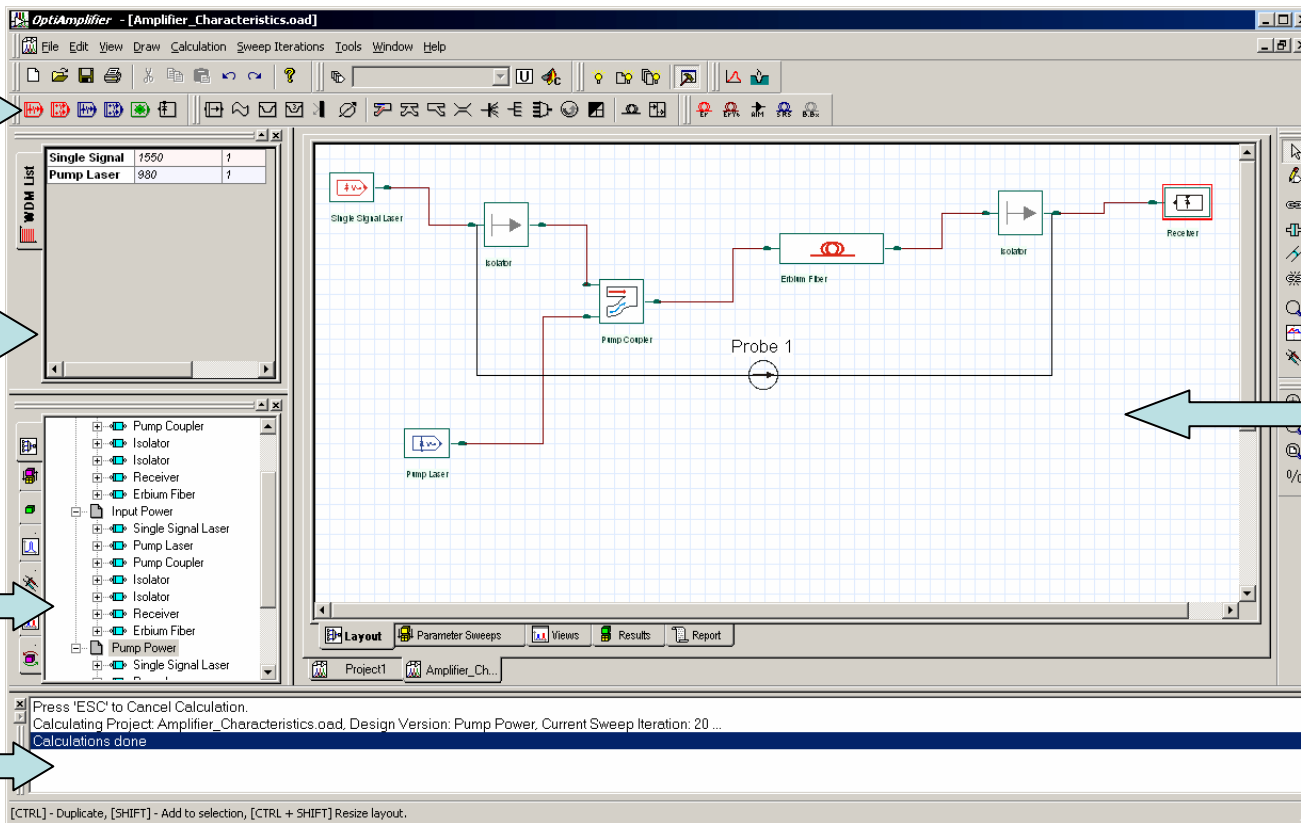
**Innovative software for the design, simulation, and optimization of optical fiber amplifiers and lasers, thus, enabling the analysis of component performance in fiber links and systems**



# Typical Applications

- **Single & multi-stage, reflective & split-band amplifiers for CATV or WDM networks**
- **Optically gain-clamped hybrid amplifiers & fiber lasers**
- **ASE broadband sources**
- **Amplified system BER and link budget calculations**
- **Amplifier parameters optimizations**

# OptiAmplifier



The screenshot shows the OptiAmplifier software interface with the following components and annotations:

- Component Library:** A toolbar at the top left containing various component icons.
- WDM List:** A table listing components and their parameters.
- Project Browser:** A tree view on the left showing the project hierarchy.
- Layout Editor:** The central workspace showing a schematic diagram of an optical amplifier.
- Output Window:** A text area at the bottom showing calculation status.

Component	Value	Unit
Single Signal	1550	nm
Pump Laser	980	nm

**Project Browser Hierarchy:**

- Input Power
- Single Signal Laser
- Pump Laser
- Pump Coupler
- Isolator
- Isolator
- Receiver
- Erbium Fiber
- Pump Power
- Single Signal Laser

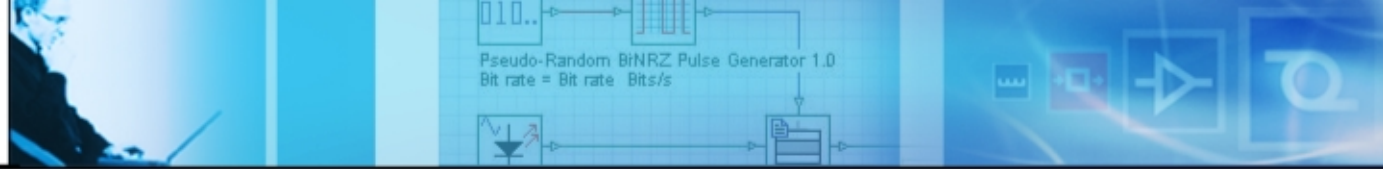
**Layout Editor Schematic:**

- Single Signal Laser
- Isolator
- Pump Coupler
- Erbium Fiber
- Isolator
- Receiver
- Pump Laser
- Probe 1

**Output Window:**

```
Press 'ESC' to Cancel Calculation.  
Calculating Project: Amplifier_Characteristics.oad, Design Version: Pump Power, Current Sweep Iteration: 20 ...  
Calculations done
```

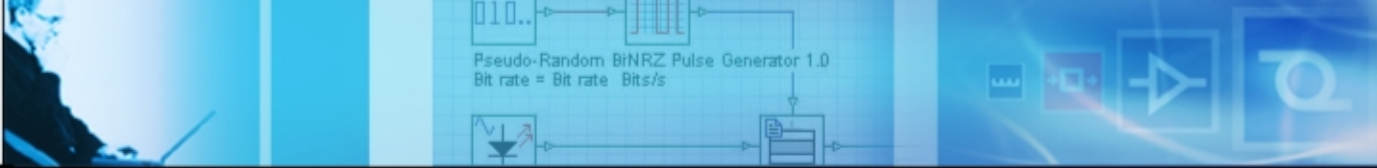
**Footer:** [CTRL] - Duplicate, [SHIFT] - Add to selection, [CTRL + SHIFT] Resize layout.



## Main Elements

- Component Library
- Bidirectional Data Flow
- GUI (Graphical User Interface)





# Active Components



**Single Signal Laser Properties**

Label:  [OK] [Cancel] [Help]

Wavelength definition:

Wavelength:  [nm]

Frequency:  [THz]

ITU Channel:  [Setup...]

Spectral width:  [nm]

Power:

[Power ON]   [mW]  [dBm]

Component filename:

[Load...] [Save As...]

**Multiple Signal Laser Properties**

Label:  [Power ON] [OK] [Cancel] [Help] [More >>]

ITU Channel	Freq. [Thz]	Wavelength [nm]	Power [dBm]	Power [mW]
approx. 11	191.897	1561.440	0.00	1.000000
approx. 10	192.097	1560.627	0.00	1.000000
approx. 9	192.197	1559.815	0.00	1.000000
approx. 8	192.297	1559.004	0.00	1.000000
approx. 7	192.398	1558.193	1.00	1.258925
approx. 6	192.497	1557.384	1.00	1.258925
approx. 5	192.598	1556.575	1.00	1.258925
approx. 4	192.697	1555.768	1.00	1.258925

Nr of signals:  [Decrease] [Increase]

Component filename:

[Load...] [Save As...]



# Active Components



**Pump Laser Properties**

Label:

Wavelength:  [nm]  
 Spectral width:  [nm]

Drive

Power:   [mW]  [dBm]  
 Current:  [mA]

Threshold:  [mA]  
 Slope:  [mW/mA]  
 Back-facet tracking:  [mA/mW]  
 Back-facet current:  [mA]

Max power alarm:  [mW]   
 Max current alarm:  [mA]

Component filename

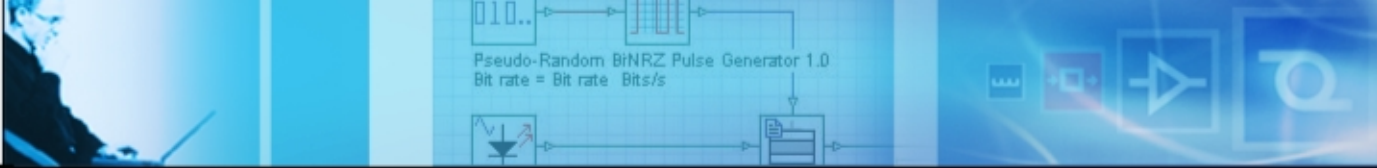
**Multiple Pump Laser Properties**

Label:

Frequency [THz]	Wavelength [nm]	Power [dBm]	Power [mW]
305.911	980.000	20.00	100.00
305.911	980.000	20.00	100.00
305.911	980.000	20.00	100.00
305.911	980.000	20.00	100.00

Nr of pumps:

Component filename



# Active Components



**White Light Source Properties**

Label:

Spectral density  
  [dBm/nm]  [mW/nm]

Component filename

**Receiver Properties**

Label:

Receiver type  
 PIN receiver  
 APD receiver

Receiver mode  
 Analog  
 Digital  
 Monitor

Wavelength  
 Independent  
 Dependent

Decision point  
 Optimum  Average  Fixed %:

Crosstalk  
 Include  
 Neglect

MPI  
 Include  
 Neglect

Receiver parameters

Signal channel:   
 Temperature:  [°C]  
 Equivalent res.:  [Ohms]  
 Bandwidth:  [GHz]  
 Dark current:  [µA]  
 RIN:  [dB/sq(Hz)]  
 ER:   
 Modulation index:   
 Laser linewidth:  [Hz]

Responsivity

Indep:  [A/W]  
 Signal:  [A/W]  
 980 nm:  [A/W]  
 1480 nm:  [A/W]

Power Alarm

Min:  [dBm]  
 Max:  [dBm]

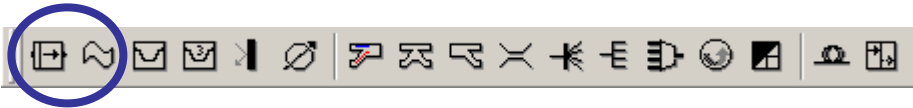
APD  
 APD gain - 'M':   
 Ionization factor:

Coupling efficiency:  [%]

Component filename



# Passive Components



**Isolator Properties**

Label:

Wavelength

Independent  
 Dependent  
 Cosine

Insertion loss

Independent:  [dB]  
Center:  [dB]  
1550 nm:  [dB]  
1480 nm:  [dB]  
980 nm:  [dB]

Return loss

Independent:  [dB]  
1550 nm:  [dB]  
1480 nm:  [dB]  
980 nm:  [dB]

Isolation

Independent:  [dB]  
Center:  [dB]  
1550 nm:  [dB]  
1480 nm:  [dB]  
980 nm:  [dB]

Cosine

Center wavelength:  [nm]  
Bandwidth:  [nm]

Component filename

**Reflective Filter Properties**

Label:

Filter model:

Filename:

Insertion loss:  [dB]  
Center wavelength:  [nm]  
Bandwidth:  [nm]  
Depth:  [dB]  
Order:   
Slope:

Insertion loss at 980 nm:  [dB]  
Insertion loss at 1480 nm:  [dB]  
Reflection at 980 nm:  [dB]  
Reflection at 1480 nm:  [dB]

Component filename



# Passive Components



**Transmission Filter Properties**

Label:

Filter model:

Filename:

Insertion loss:  [dB]

Center wavelength:  [nm]

Bandwidth:  [nm]

Depth:  [dB]

Order:

Slope:

Insertion loss at 980 nm:  [dB]

Insertion loss at 1480 nm:  [dB]

Return loss:  [dB]

Component filename:

**3 Port Filter Properties**

Label:

Filter model:

Center wavelength:  [nm]

Bandwidth:  [nm]

Order:

Slope:

Transmission [ 1 -> 3 ]

Filename:

Insertion loss:  [dB]

Insertion loss at 980 nm:  [dB]

Insertion loss at 1480 nm:  [dB]

Depth:  [dB]

Reflection [ 1 -> 2 ]

Filename:

Insertion loss:  [dB]

Insertion loss at 980 nm:  [dB]

Insertion loss at 1480 nm:  [dB]

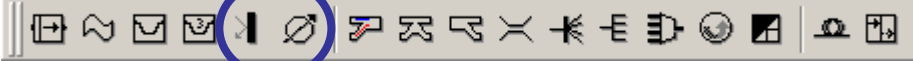
Depth:  [dB]

Return loss:  [dB]

Component filename:



# Passive Components



**Variable Reflector Properties**

Label:

Wavelength

Independent  
 Dependent

Insertion Loss

Independent:	<input type="text" value="0.1"/>	[dB]
1550 nm:	<input type="text" value="0.1"/>	[dB]
1480 nm:	<input type="text" value="0.1"/>	[dB]
980 nm:	<input type="text" value="0.1"/>	[dB]

Reflection

Independent:	<input type="text" value="-100"/>	[dB]
1550 nm:	<input type="text" value="-100"/>	[dB]
1480 nm:	<input type="text" value="-100"/>	[dB]
980 nm:	<input type="text" value="-100"/>	[dB]

Component filename

**Variable Attenuator Properties**

Label:

Wavelength

Independent  
 Dendendent

Insertion Loss

Independent:	<input type="text" value="0.1"/>	[dB]
1550 nm:	<input type="text" value="0.1"/>	[dB]
1480 nm:	<input type="text" value="0.1"/>	[dB]
980 nm:	<input type="text" value="0.1"/>	[dB]

Return Loss

Independent:	<input type="text" value="60"/>	[dB]
1550 nm:	<input type="text" value="60"/>	[dB]
1480 nm:	<input type="text" value="60"/>	[dB]
980 nm:	<input type="text" value="60"/>	[dB]

Component filename



# Passive Components



**Pump Coupler Properties**

Label:

Wavelength

Independent  
 Dependent  
 Cosine

Coupler wavelength

980 nm  
 1480 nm

Insertion loss

Independent:  [dB]  
 Pump:  [dB]  
 Other pump band:  [dB]  
 1550 nm:  [dB]

Return loss

Independent:  [dB]  
 Pump:  [dB]  
 Other pump band:  [dB]  
 1550 nm:  [dB]

Isolation

Independent:  [dB]  
 Pump:  [dB]  
 Other pump band:  [dB]  
 1550 nm:  [dB]

Cosine

Signal center wavelength:  [nm]  
 Signal bandwidth:  [nm]  
 Pump center wavelength:  [nm]  
 Pump bandwidth:  [nm]

Component filename

**2x2 Coupler Properties**

Label:

Wavelength

Independent  
 Dependent  
 Cosine

Insertion loss

Independent:  [dB]  
 1550 nm:  [dB]  
 1480 nm:  [dB]  
 980 nm:  [dB]

Return loss

Independent:  [dB]  
 1550 nm:  [dB]  
 1480 nm:  [dB]  
 980 nm:  [dB]

Coupling percentage

Independent:  [%]  
 1550 nm:  [%]  
 1480 nm:  [%]  
 980 nm:  [%]

Cosine

Center wavelength:  [nm]  
 Bandwidth:  [nm]

Component filename



# Passive Components



**Tap Properties**

Label:

Tap percentage:

Wavelength

Independent  
 Dependent  
 Cosine

Insertion loss

Independent:	<input type="text" value="0.1"/> [dB]
1550 nm:	<input type="text" value="0.1"/> [dB]
1480 nm:	<input type="text" value="0.1"/> [dB]
980 nm:	<input type="text" value="0.1"/> [dB]

Return Loss

Independent:	<input type="text" value="60"/> [dB]
1550 nm:	<input type="text" value="60"/> [dB]
1480 nm:	<input type="text" value="60"/> [dB]
980 nm:	<input type="text" value="60"/> [dB]

Cosine

Center wavelength:  [nm]

Bandwidth:  [nm]

Component filename

**2x2 Switch Properties**

Label:

Insertion loss:  [dB]

Return loss:  [dB]

Isolation:  [dB]

Switch State

Bar  Cross

Component filename



# Passive Components



**1xN Switch Properties**

Label:

Insertion loss:  [dB]

Return loss:  [dB]

Isolation:  [dB]

Number of output ports:

Selected output port:

Component filename:

OK  
Cancel  
Help  
Load...  
Save As...

**1x4 Splitter Properties**

Label:

Wavelength:

- Independent
- Dependent
- Cosine

Insertion loss:

Independent:	<input type="text" value="0.1"/> [dB]
1550 nm:	<input type="text" value="0.1"/> [dB]
1480 nm:	<input type="text" value="0.1"/> [dB]
980 nm:	<input type="text" value="0.1"/> [dB]

Return loss:

Independent:	<input type="text" value="60"/> [dB]
1550 nm:	<input type="text" value="50"/> [dB]
1480 nm:	<input type="text" value="50"/> [dB]
980 nm:	<input type="text" value="50"/> [dB]

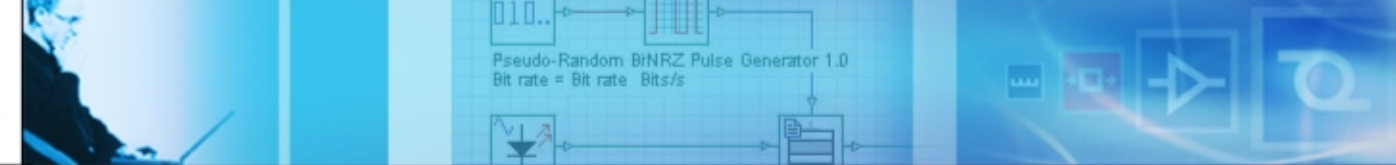
Cosine:

Center wavelength:  [nm]

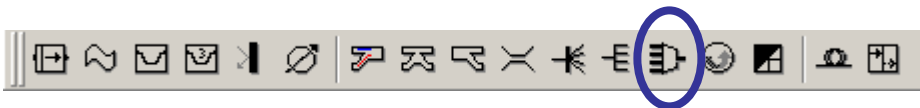
Bandwidth:  [nm]

Component filename:

OK  
Cancel  
Help  
Load...  
Save As...



# Passive Components



**Multiplexer/Demultiplexer Properties**

Label:

Return loss:  [dB]

Channel spacing:

Filter bandwidth:   [nm]  [GHz]

Filter depth:  [dB]

Signal insertion loss:  [dB]

Pump insertion loss at 980 nm:  [dB]

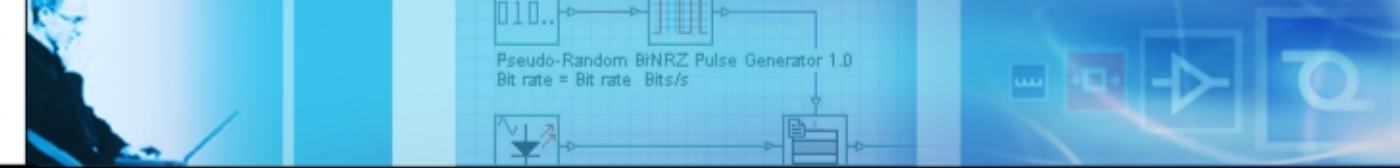
Pump insertion loss at 1480 nm:  [dB]

Channel 1:  [nm]

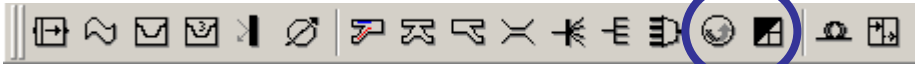
Number of channels:

Channel	Wavelength (nm)	Ripple (dB)
Channel 1	1560	0
Channel 2	1560	0
Channel 3	1560	0
Channel 4	1560	0

Component filename:



# Passive Components



**Circulator Properties**

Label:  OK  
Cancel  
Help

Wavelength

Independent  
 Dependent  
 Cosine

Insertion loss

Independent:  [dB]  
Center:  [dB]  
1550 nm:  [dB]  
1480 nm:  [dB]  
980 nm:  [dB]

Return loss

Independent:  [dB]  
1550 nm:  [dB]  
1480 nm:  [dB]  
980 nm:  [dB]

Isolation

Independent:  [dB]  
Center:  [dB]  
1550 nm:  [dB]  
1480 nm:  [dB]  
980 nm:  [dB]

Cosine

Center wavelength:  [nm]  
Bandwidth:  [nm]

Component filename

Load... Save As...

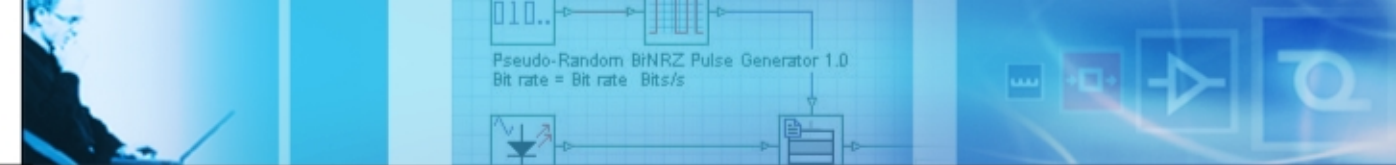
**Polarization Combiner Properties**

Label:  OK  
Cancel  
Help

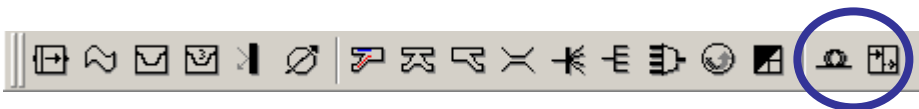
Signal insertion loss:  [dB]  
Pump insertion loss at 980 nm:  [dB]  
Pump insertion loss at 1480 nm:  [dB]  
Return loss:  [dB]

Component filename

Load... Save As...



# Passive Components



**Fiber Link Properties**

Label:

Length:  [km]

Rayleigh backscattering at 1000 nm:  [dB/km]

Capture percent:  [%]

Hydroxide absorption peak wavelength:  [nm]

Hydroxide peak absorption:  [dB/km]

Hydroxide width:  [nm]

Infrared peak wavelength:  [um]

Infrared peak absorption:  [dB/km]

Splice loss:  [dB/km]

Wavelength:  [nm]

Total loss:  [dB]

Total return loss:  [dB]

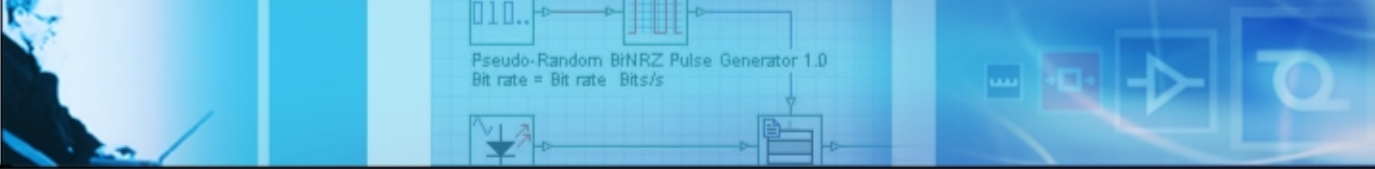
Component filename:

**Multi Path Interference Converter Properties**

Label:

Channel number:

Component filename:



# Active Fiber Models



**Erbium Doped Fiber Properties**

Label:

OK  
Cancel  
Help

Main | Algorithm | Calculation | Enhanced | Temperature

Core radius:  [um]  
 Er radius:  [um]  
 Ion density:  [m<sup>-3</sup>]  
 Loss at 1300 nm:  [dB/km]  
 Metastable lifetime:  [ns]  
 Numerical aperture:   
 Length:  [m]

Graph properties...

Cross section filename:  
 Load..

Component filename:  
 Load.. Save As... Encrypt..

Main | Algorithm | Calculation | Enhanced | Temperature

Calculation algorithm:  Equivalent ASE  
 Geometrical model:   
 Confinement factor:    
 Number of transverse integrations:

Main | Algorithm | Calculation | Enhanced | Temperature

Maximum iterations:   
 Nr. of distance steps:   
 Relative tolerance:

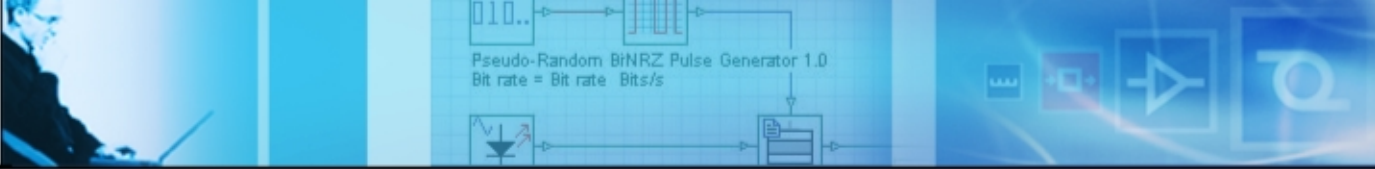
Main | Algorithm | Calculation | Enhanced | Temperature

Rayleigh backscattering constant  
 Constant:  [dB/km]  
 Back scatter capture:  [%]

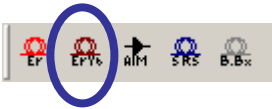
Concentration quenching  
  
 Upconversion coeff.:  [m<sup>3</sup>/s]  
 Ions per cluster:   
 Relative nr. of clusters:  [%]

Main | Algorithm | Calculation | Enhanced | Temperature

include temperature effects  
 Cross section temperature:  [°C]  
 Temperature:  [°C]



# Active Fiber Models



**Erbium Ytterbium Codoped Fiber Properties**

Label:

OK  
Cancel  
Help

Main | Doping | Calculation | Enhanced

Core radius:  [um]  
 Doped radius:  [um]  
 Numerical aperture:   
 Length:  [m]

Loss

Signal:  [dB/m]  
 Pump:  [dB/m]

Graph properties...

Erbium cross section filename  
 Load...

Ytterbium cross section filename  
 Load...

Component filename  
 Load... Save As...

Main | Doping | Calculation | Enhanced

Ion density

Erbium:  [m<sup>-3</sup>]  
 Ytterbium:  [m<sup>-3</sup>]

Metastable lifetime

Erbium:  [ms]  
 Ytterbium:  [ms]

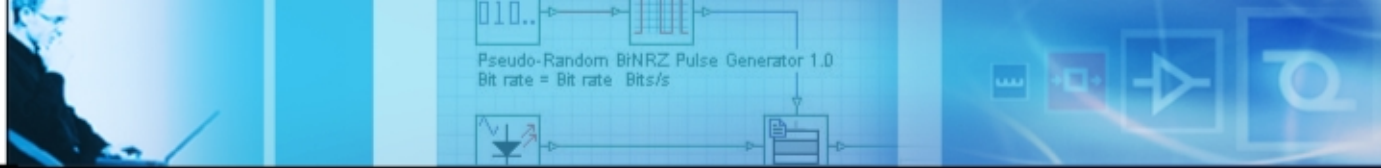
Main | Doping | Calculation | Enhanced

Maximum iterations:   
 Nr. of distance steps:   
 Relative tolerance:   
 Nr. of radial steps:

Main | Doping | Calculation | Enhanced

Auto

Upconversion:  [m<sup>3</sup>/s]  
 C16:  [m<sup>3</sup>/s]  
 C14:  [m<sup>3</sup>/s]  
 A32:  [1/s]  
 A43:  [1/s]



# Active Fiber Models



**Erbium Doped Fiber - Average Inversion Model Properties**

Label:

Ion density  
  [ppm]  [m<sup>-3</sup>]

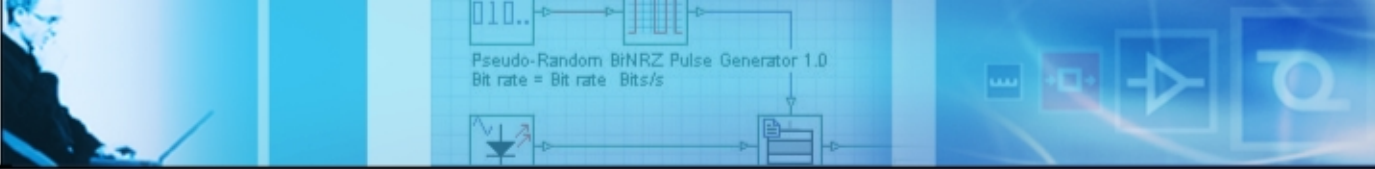
Control method  
 Power  [dBm]  
 Gain  [dB]  
 Inversion

Input loss:  [dB]  
Other loss:  [dB]  
Length:  [m]  
Total isolation:  [dB]

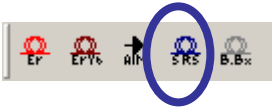
Cross section filename

Filter filename

Component filename



# Active Fiber Models



**Raman Amplifier**

Label: Raman Amplifier

Reflections: Fiber | Effects On/Off: Raman Effect | Simulation Details: Rayleigh Effect | Results: Other Nonlinearities

Fiber length: 10 [km]

Attenuation:  Constant  Wavelength dependent/From file  
 Attenuation - constant: 0.25 [dB/km]  
 Attenuation vs. wavelength: AttVSLambda.dat

Eff. area:  Constant  Wavelength dependent/From file  
 Eff. area - constant: 72 [microns<sup>2</sup>]  
 Eff. area vs. wavelength: EffAreaVSLambda.dat

Forward input coupling loss: -1 [dB]  
 Forward output coupling loss: -0.022 [dB]  
 Backward input coupling loss: -1 [dB]  
 Backward output coupling loss: -0.022 [dB]

Component filename:

Reflections: Fiber | Effects On/Off: Raman Effect | Simulation Details: Rayleigh Effect | Results: Other Nonlinearities

Peak Raman gain coef.: 9.9e-014 [m/W]  
 Pump wavelength of peak Raman gain coef.: 1000 [nm]  
 Raman gain polarization factor: 0.5  
 Temperature: 300 [K]

Raman gain spectrum vs. freq.: RamanGainVsFreq.dat

Reflections: Fiber | Effects On/Off: Raman Effect | Simulation Details: Rayleigh Effect | Results: Other Nonlinearities

Rayleigh:  Constant  Wavelength dependent/From file  
 Rayleigh coef. - constant: 0.0005 [1/km]  
 Rayleigh coef vs. wavelength: RayleighGainVSLambda.dat

Reflections: Fiber | Effects On/Off: Raman Effect | Simulation Details: Rayleigh Effect | Results: Other Nonlinearities

Attenuation:  ON  OFF  
 Rayleigh back-scattering gain:  ON  OFF  
 SRS gain (Stimulated Raman scattering gain):  ON  OFF  
 SpRS gain (Spontaneous Raman scattering gain):  ON  OFF  
 Pump depletion in SRS:  ON  OFF  
 Multiple Rayleigh back-scattering:  ON  OFF  
 Left end reflection:  ON  OFF  
 Right end reflection:  ON  OFF  
 SBS gain (Stimulated Brillouin scattering gain):  ON  OFF  
 Pump depletion in SBS:  ON  OFF  
 FWM (four - wave mixing):  ON  OFF  
 Nonlinear contribution to the phase-mismatch:  ON  OFF

Reflections: Fiber | Effects On/Off: Raman Effect | Simulation Details: Rayleigh Effect | Results: Other Nonlinearities

Brillouin:  Constant  Wavelength dependent/From file  
 Brillouin Bandwidth - Constant: 40 [MHz]  
 Brillouin Bandwidth vs. wavelength: BrillouinBWVSLambda.dat   
 Brillouin gain coef.: 5e-011 [m/W]  
 Brillouin gain polarization factor: 0.66  
 Brillouin Stokes shift: 11 [GHz]

Nonlinear refr. index:  Constant  Wavelength dependent/From file  
 Nonlinear refr. index - Constant: 3e-020 [m<sup>2</sup>/W]  
 Nonlinear refr. index vs. wavelength: NonlinearRefrIndexVSLambda.dat   
 Raman - resonant n2 dispersion: RamanRefrIndexVSLambda.dat

Dispersion:  
 Eff. refr. index vs. wavelength: EffRefrIndexVSLambda.dat   
 Group velocity dispersion: 5 [ps/nm/km]  
 Dispersion slope: 0.1 [ps/nm<sup>2</sup>/km]

Reflections: Fiber | Effects On/Off: Raman Effect | Simulation Details: Rayleigh Effect | Results: Other Nonlinearities

Lower limit of region of interest: 1550 [nm]  
 Upper limit of region of interest: 1600 [nm]

Reflections: Fiber | Effects On/Off: Raman Effect | Simulation Details: Rayleigh Effect | Results: Other Nonlinearities

Left end:  Constant  Wavelength dependent/From file  
 Left end reflection - constant: -30 [dB]  
 Left end reflection vs. wavelength: LeftEndRefrVSLambda.dat

Right end:  Constant  Wavelength dependent/From file  
 Right end reflection - constant: -30 [dB]  
 Right end reflection vs. wavelength: RightEndRefrVSLambda.dat

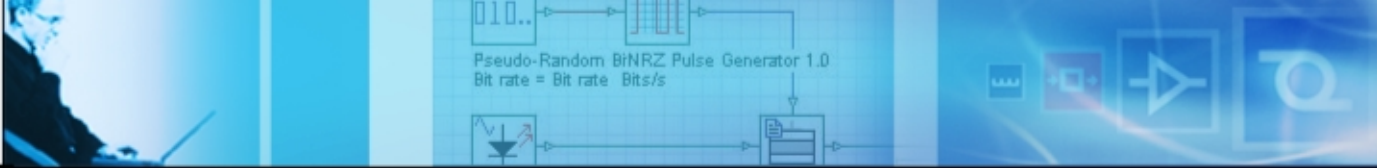
Reflections: Fiber | Effects On/Off: Raman Effect | Simulation Details: Rayleigh Effect | Results: Other Nonlinearities

Parameter set:  Enable  Disable  
 User  Auto  Default

Power accuracy: 0.001  
 Max. number of iterations: 100  
 Number of power iterations: 5

ODE integration method:  
 Fifth-order Runge-Kutta with step size control  Gear stiff eq. solver with step size control

ODE integrator accuracy: 1e-006  
 Max. number of steps per iteration: 100000  
 Number of longitudinal points: 256  
 Background noise level: 1e-100 [W]  
 Inphase noise ratio: 0



# Active Fiber Models



**Erbium Doped Fiber Black Box Properties**

Label:

Length:  [m]

Calculation

Maximum iterations:

Nr. of distance steps:

Relative tolerance:

Graph properties...

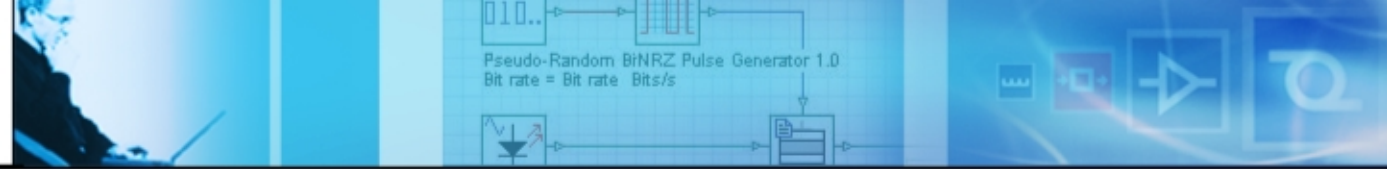
Component filename

**Decrypt**

Company list:

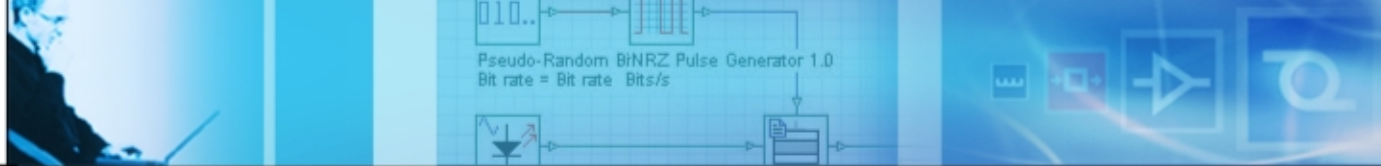
Source file:  ...

Password:



# Bidirectional Data Flow

- Effects of reflections and return losses
- MPI (Multi path interference)

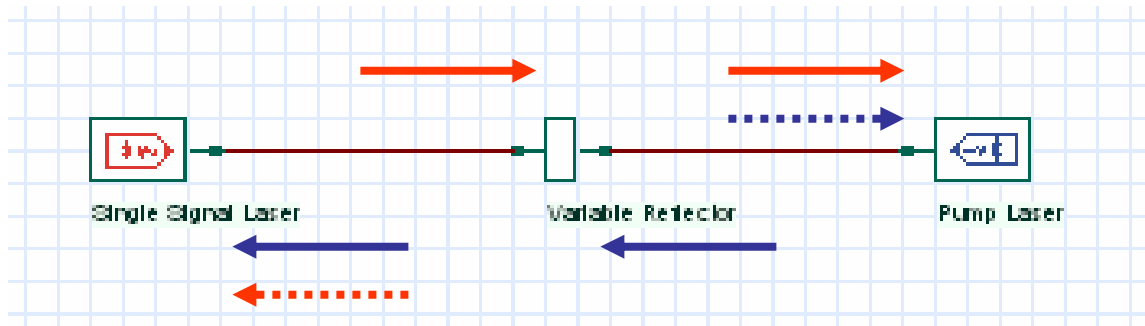


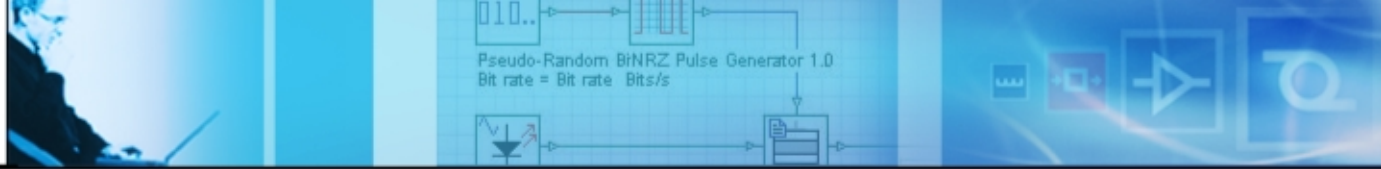
# Signal Representation

————→ Signal without reflections

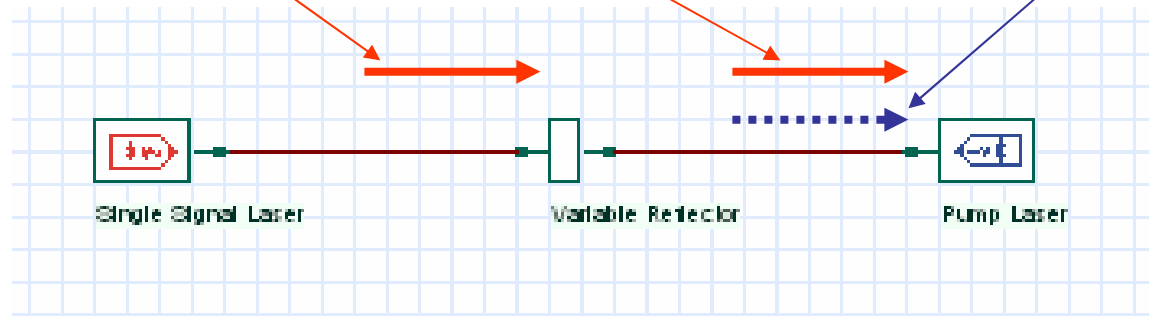
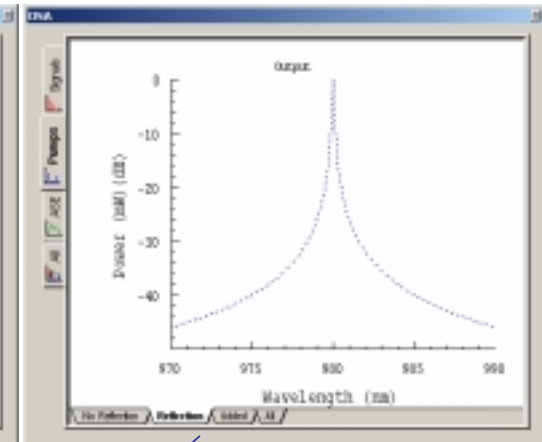
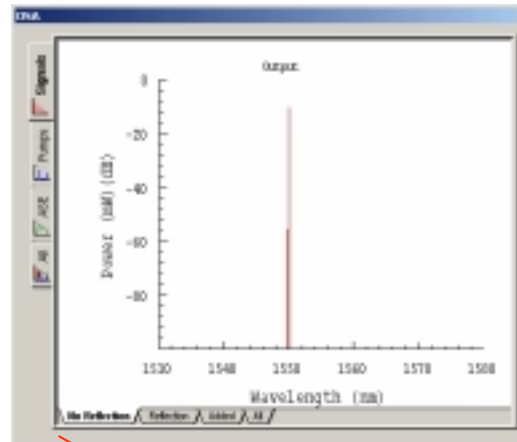
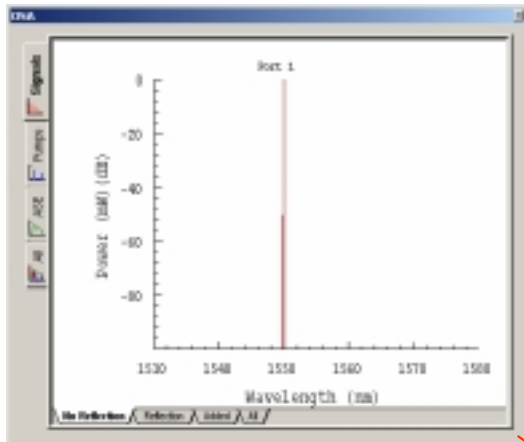
.....→ Signal from reflections

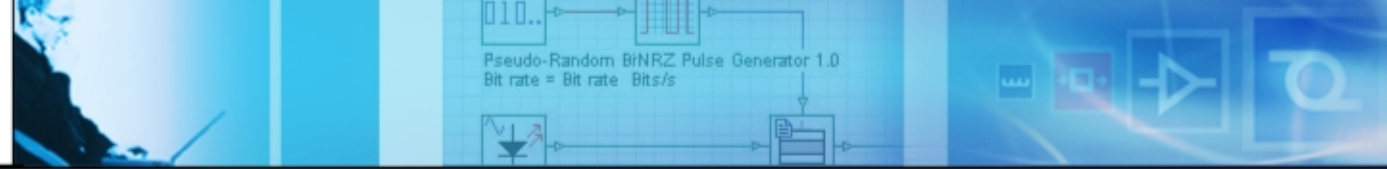
Iteration 1



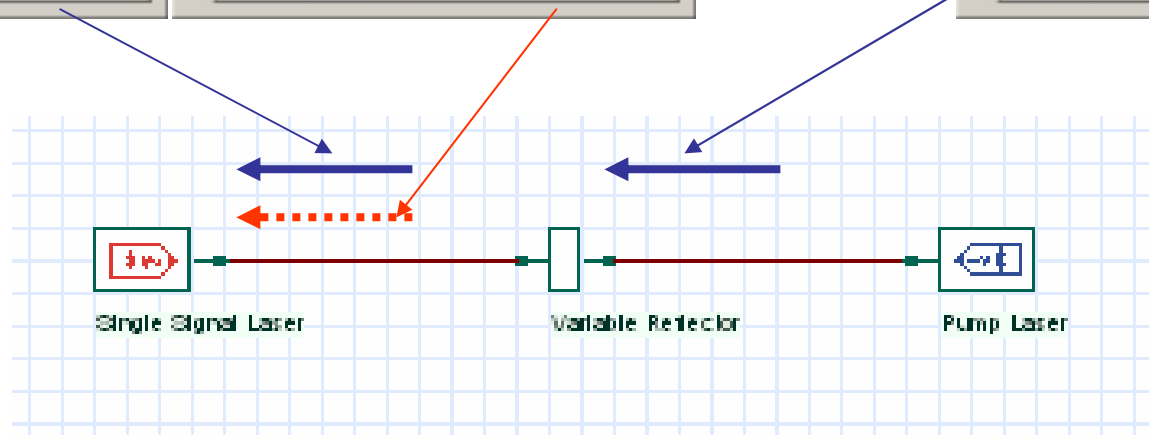
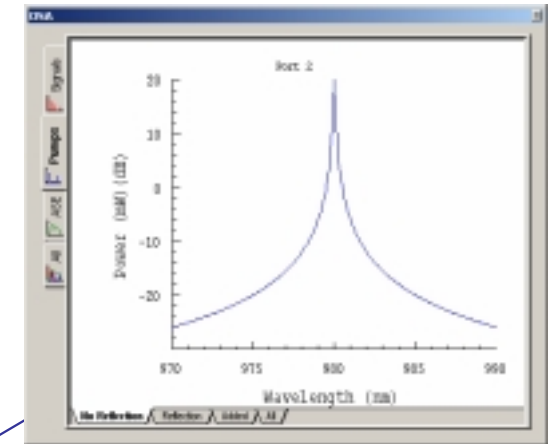
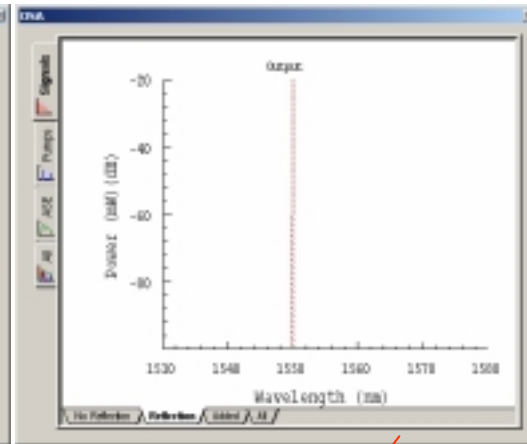
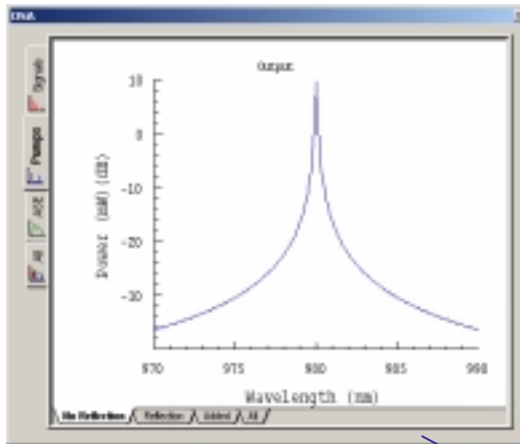


# Signal Representation

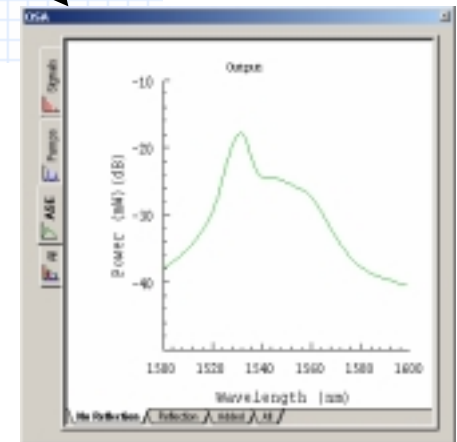
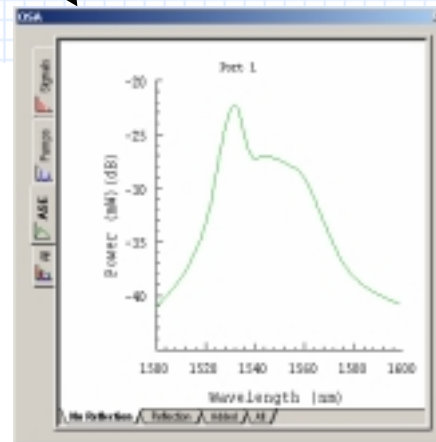
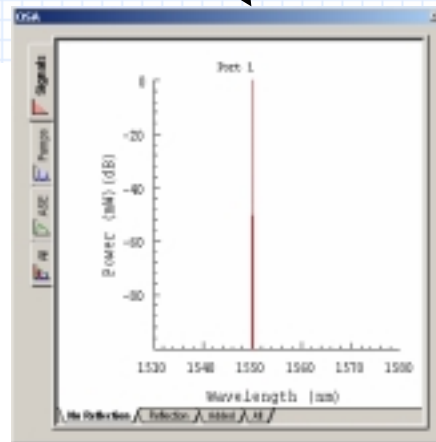
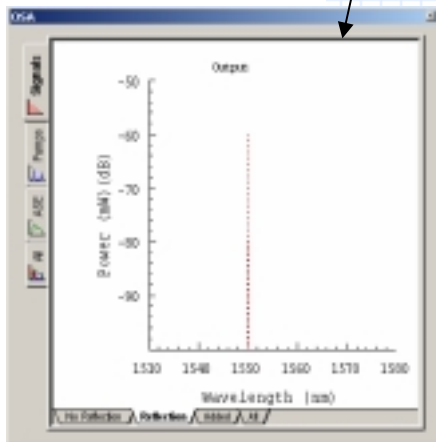
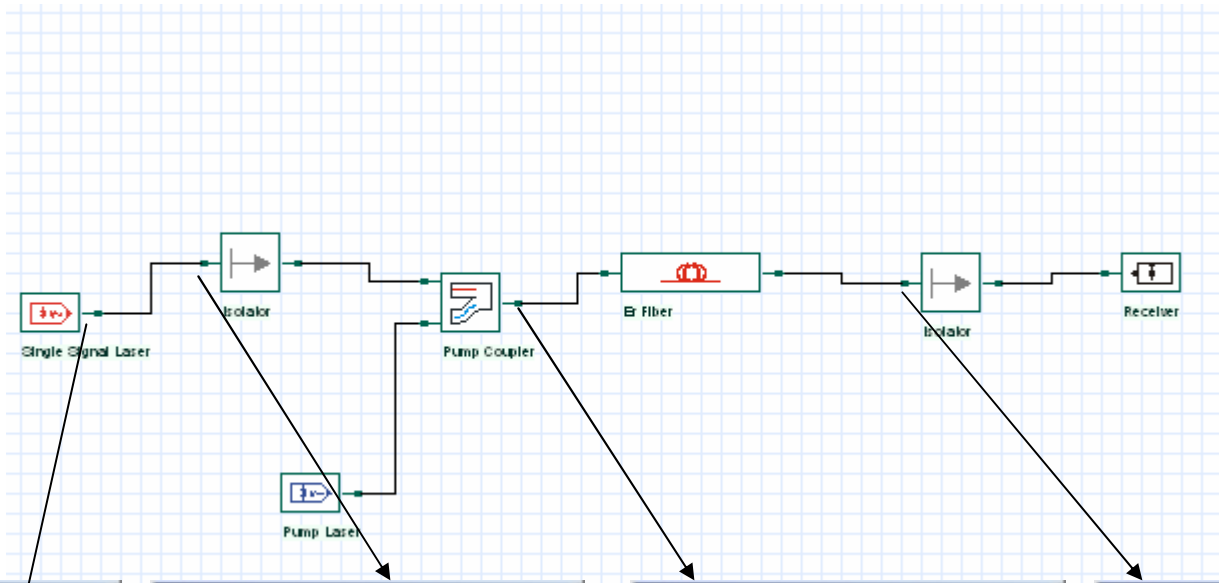


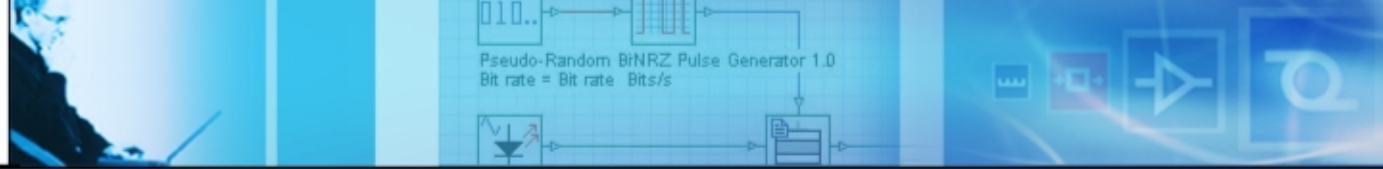


# Signal Representation



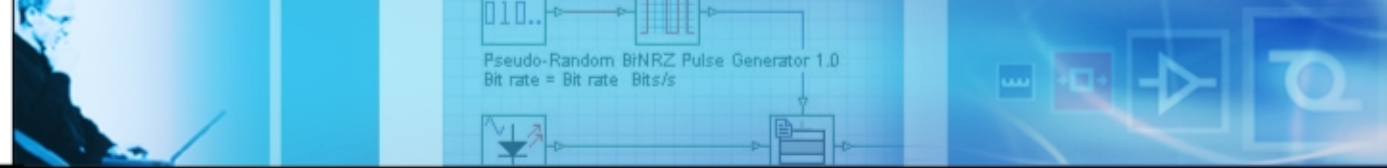
# Signal Representation





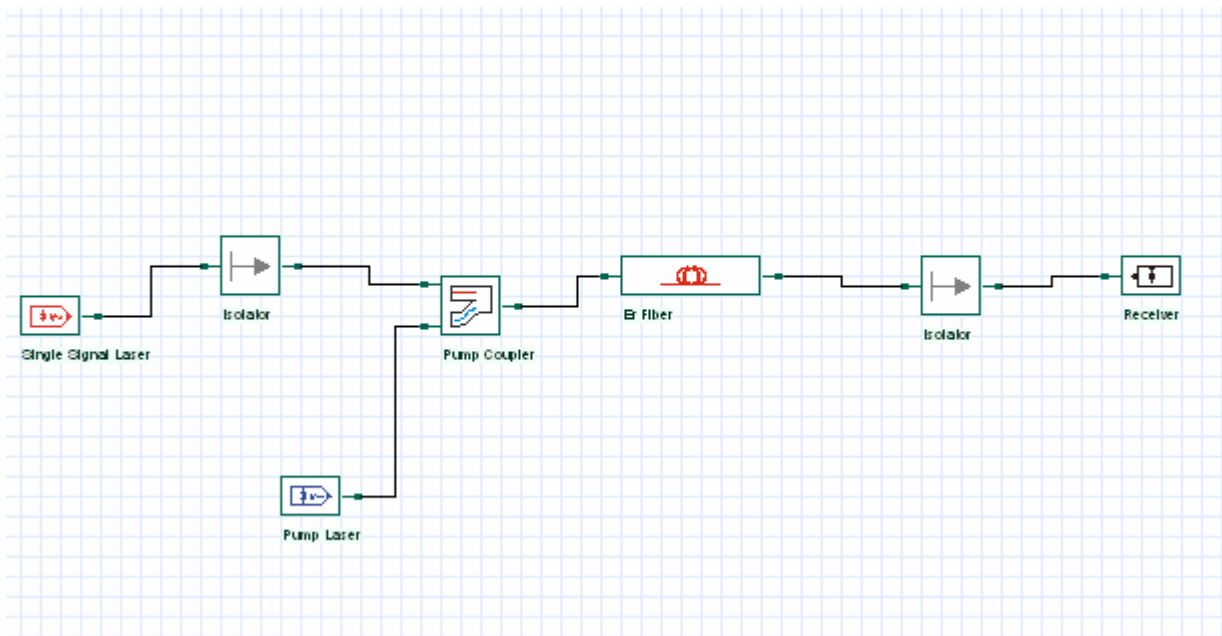
# Designing Optical Amplifiers

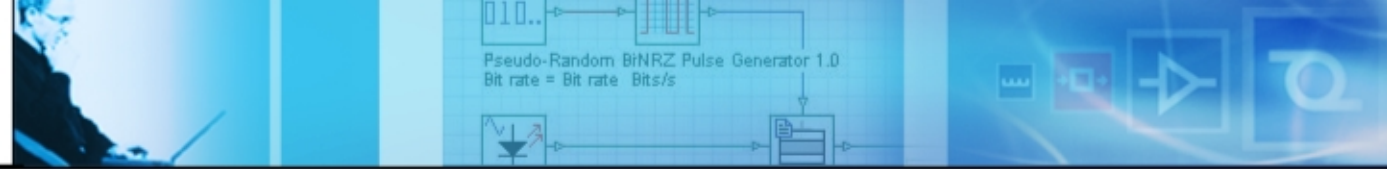
- Choose a configuration
- Draw the layout
- Set the parameters for the active and passive components
- Set the parameters for fibers
- Simulate
- Analyze results
- Optimize amplifier parameters
- Comparing Results with Measurements



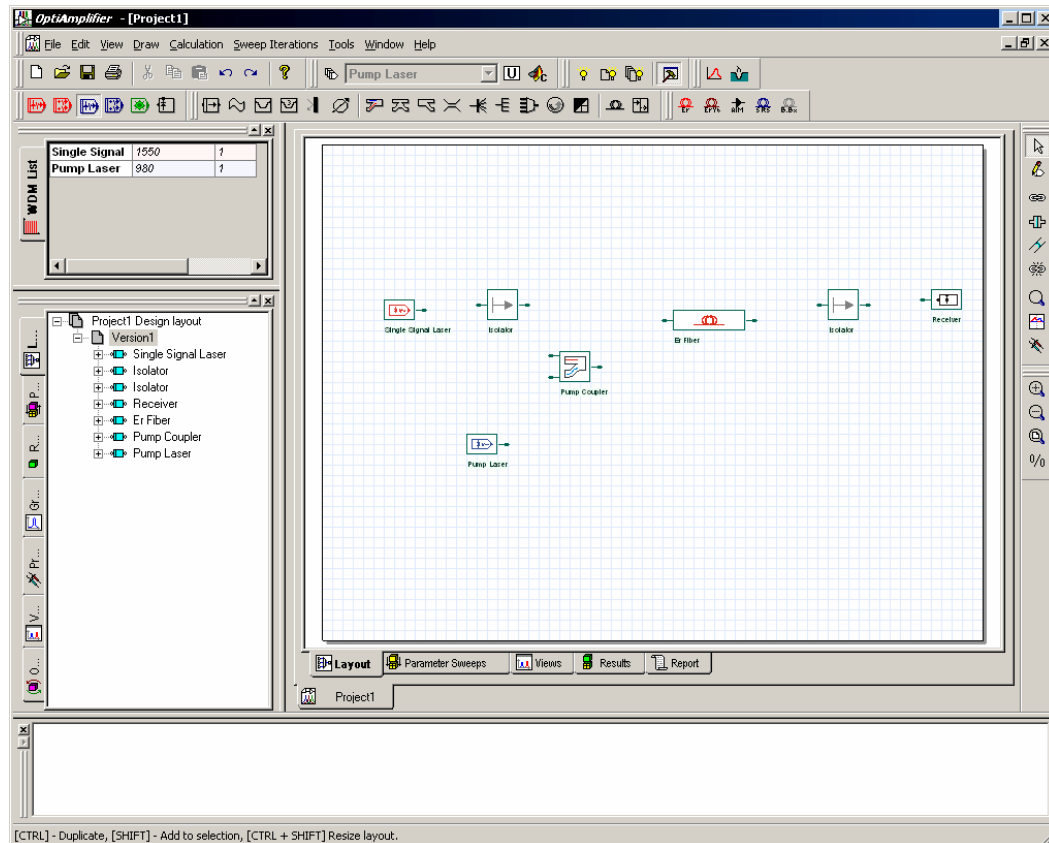
# Choosing a configuration

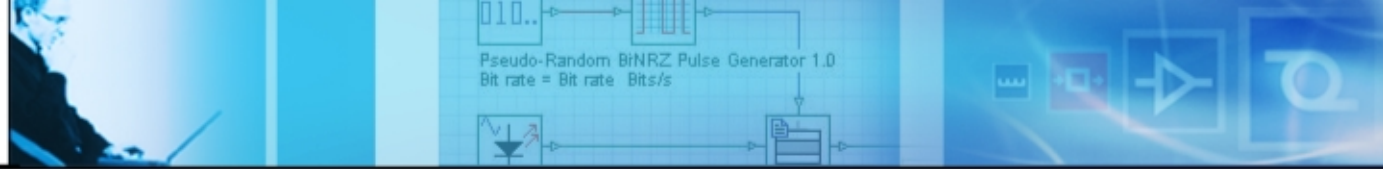
- Popular C-band configuration
- Co-propagating pump



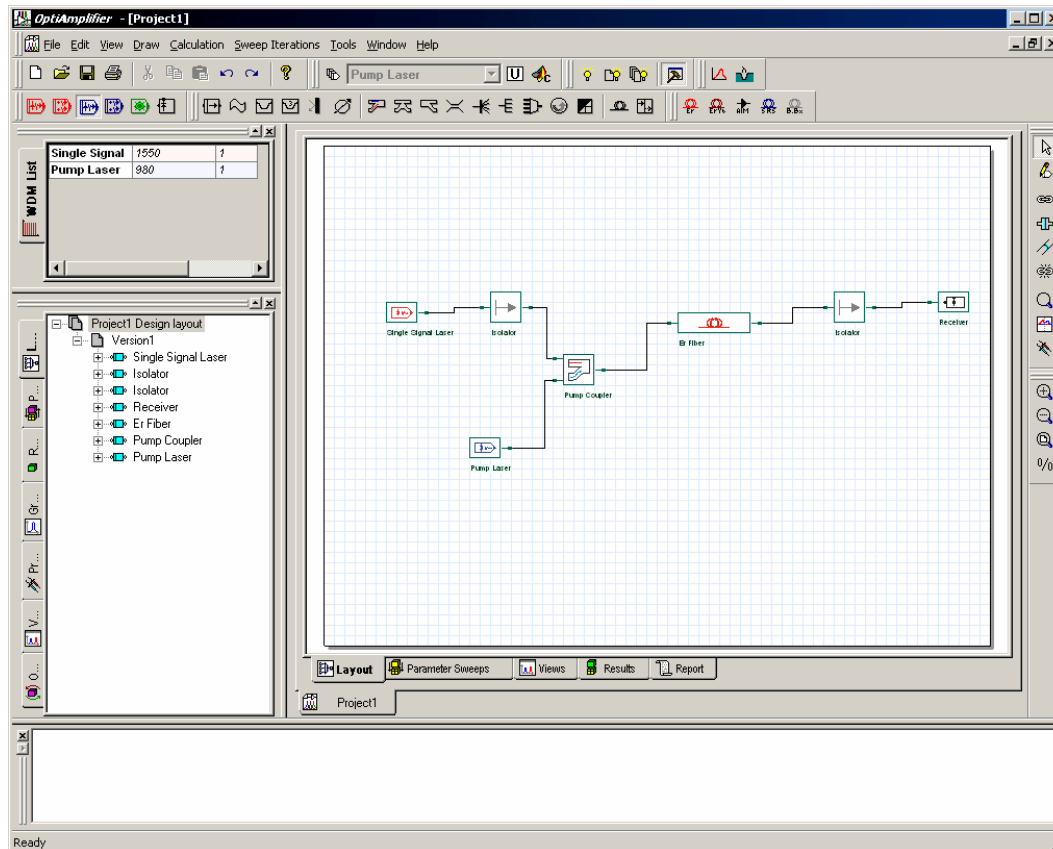


# Drawing the Layout - Components





# Drawing the Layout - Components



# Active devices

**Single Signal Laser Properties**

Label:

Wavelength definition:

Wavelength:  [nm]  
 Frequency:  [THz]  
 ITU Channel:

Spectral width:  [nm]

Power:

[mW]  [dBm]

Component filename:

**Pump Laser Properties**

Label:

Wavelength:  [nm]  
Spectral width:  [nm]

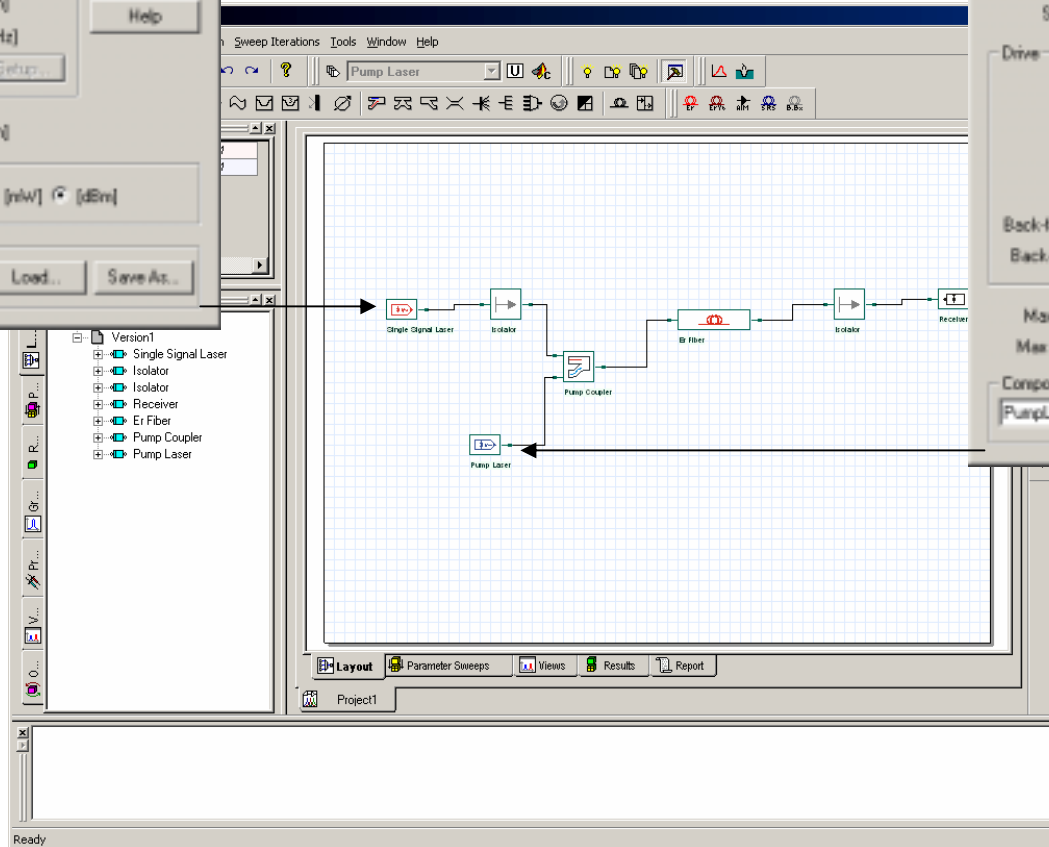
Drive:

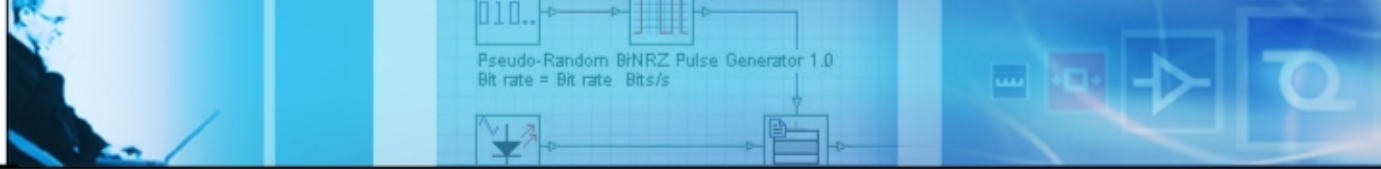
Power:   [mW]  [dBm]  
 Current:  [mA]

Threshold:  [mA]  
Slope:  [mW/mA]  
Back-facet tracking:  [mA/mW]  
Back-facet current:  [mA]

Max power alarm:  [mW]   
Max current alarm:  [mA]

Component filename:





# Passive devices

**Isolator Properties**

Label: Isolator

Wavelength:

- Independent
- Dependent
- Cosine

Insertion loss:

Independent:	0.5 [dB]
Center:	1 [dB]
1550 nm:	3 [dB]
1480 nm:	3 [dB]
980 nm:	20 [dB]

Return loss:

Independent:	60 [dB]
1550 nm:	50 [dB]
1480 nm:	50 [dB]
980 nm:	50 [dB]

Isolation:

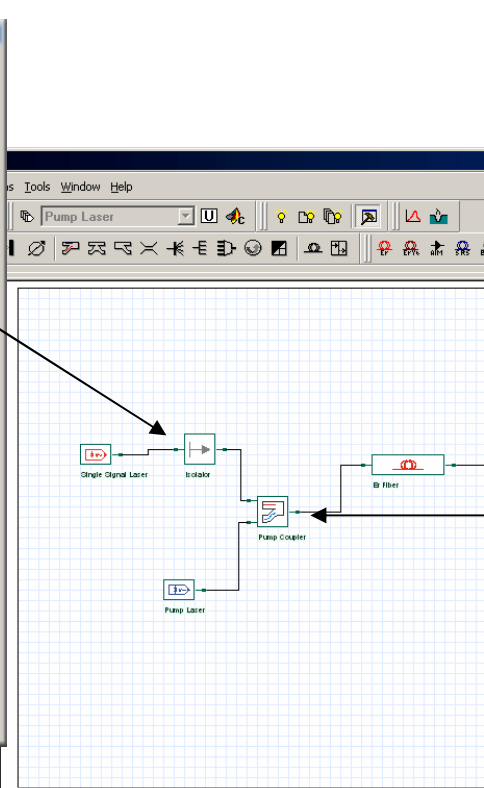
Independent:	32 [dB]
Center:	30 [dB]
1550 nm:	20 [dB]
1480 nm:	30 [dB]
980 nm:	20 [dB]

Cosine:

Center wavelength: 1550 [nm]

Bandwidth: 30 [nm]

Component Name: Isolator1.opi



**Pump Coupler Properties**

Label: Pump Coupler 980 nm

Wavelength:

- Independent
- Dependent
- Cosine

Coupler wavelength:

- 980 nm
- 1480 nm

Insertion loss:

Independent:	0.1 [dB]
Pump:	0.2 [dB]
Other pump band:	0.2 [dB]
1550 nm:	0.2 [dB]

Return loss:

Independent:	55 [dB]
Pump:	50 [dB]
Other pump band:	50 [dB]
1550 nm:	50 [dB]

Isolation:

Independent:	30 [dB]
Pump:	30 [dB]
Other pump band:	30 [dB]
1550 nm:	30 [dB]

Cosine:

Signal center wavelength: 1550 [nm]

Signal bandwidth: 30 [nm]

Pump center wavelength: 980 [nm]

Pump bandwidth: 30 [nm]

Component Name: PumpCoupler1.coup

Project1

Layout | Parameter Sweeps | Views | Results | Report

Ready

# Erbium doped fiber parameters

**Erbium Doped Fiber Properties**

Label: Er Fiber

OK  
Cancel  
Help

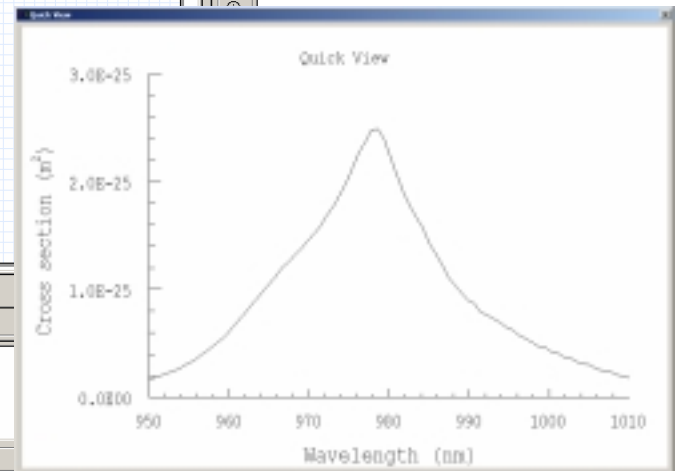
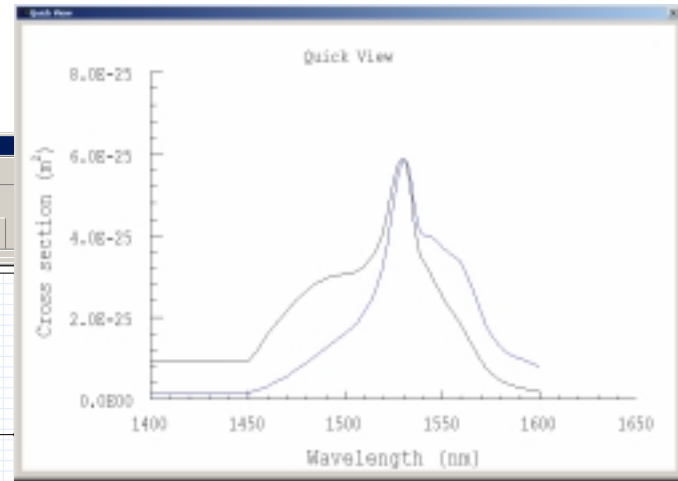
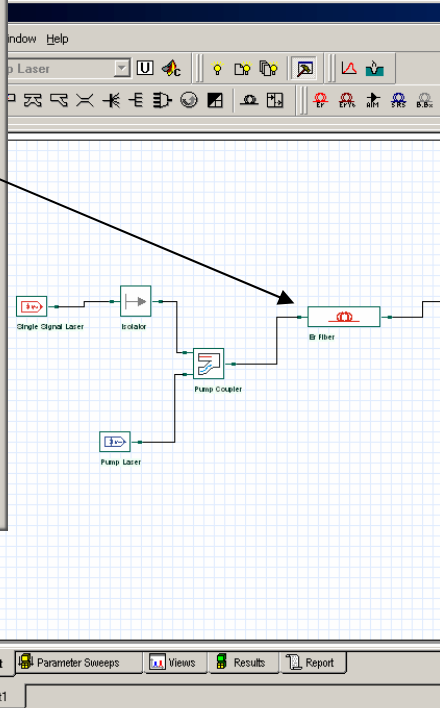
Main | Algorithm | Calculation | Enhanced | Temperature

Core radius: 1.5 [μm]  
Er radius: 1.5 [μm]  
Ion density: 3.085e+024 [m<sup>-3</sup>]  
Loss at 1300 nm: 6 [dB/km]  
Metastable lifetime: 10 [ns]  
Numerical aperture: 0.26  
Length: 15 [m]

Graph properties...

Cross section filename  
Giles.ora Load...

Component filename  
Fiber1.edf Load... Save As... Encrypt...

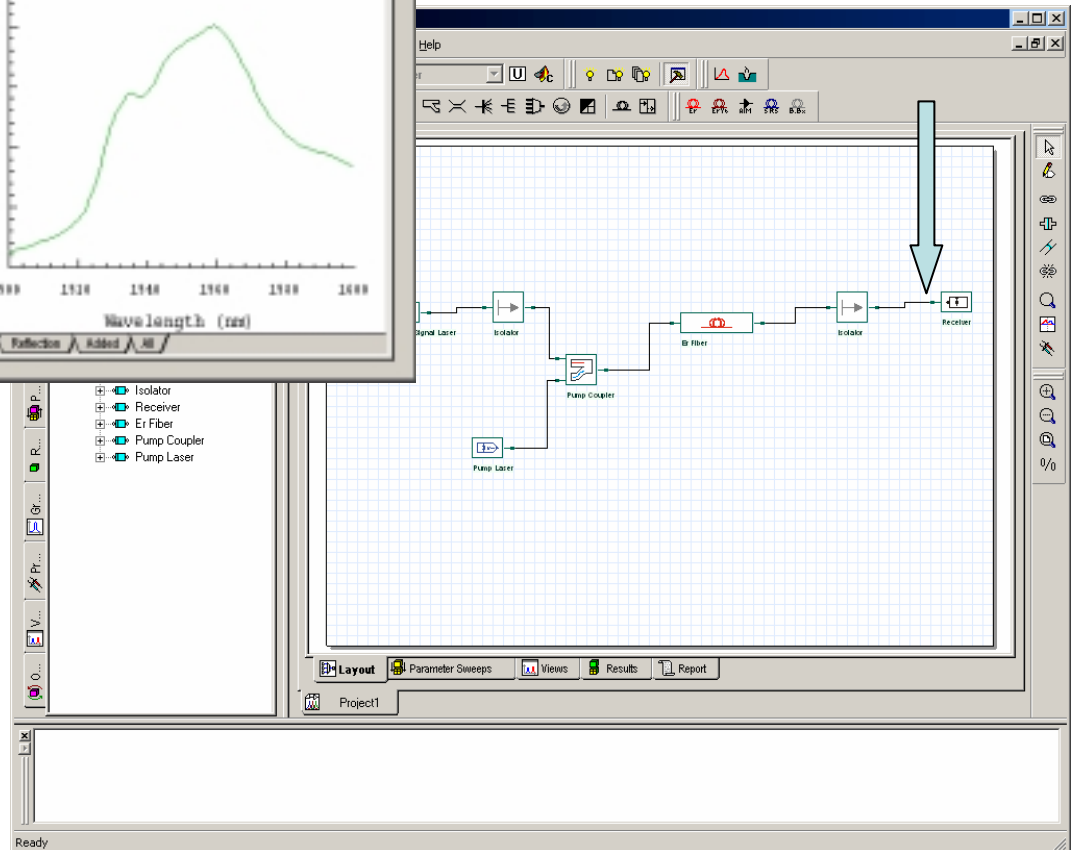
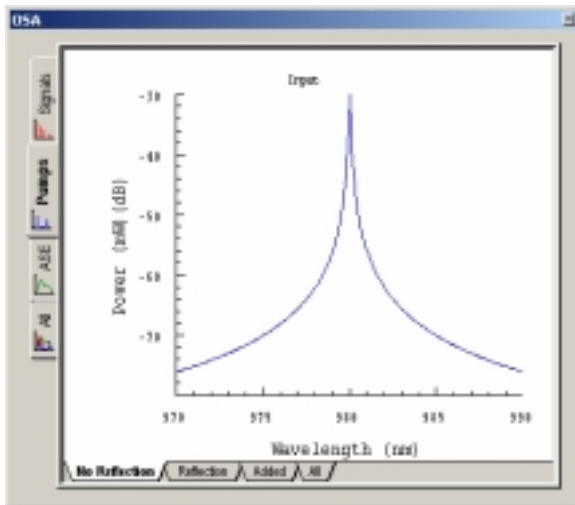
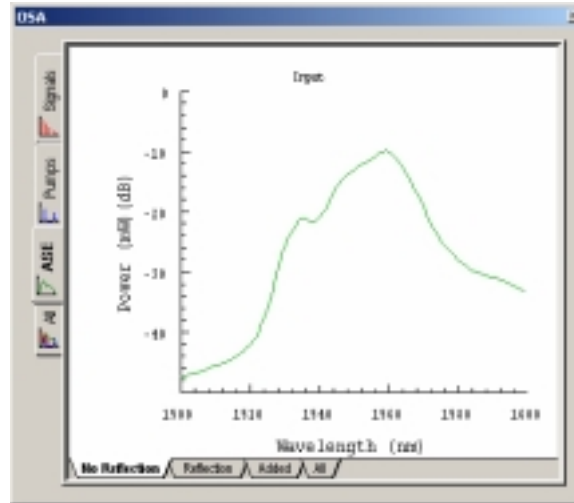
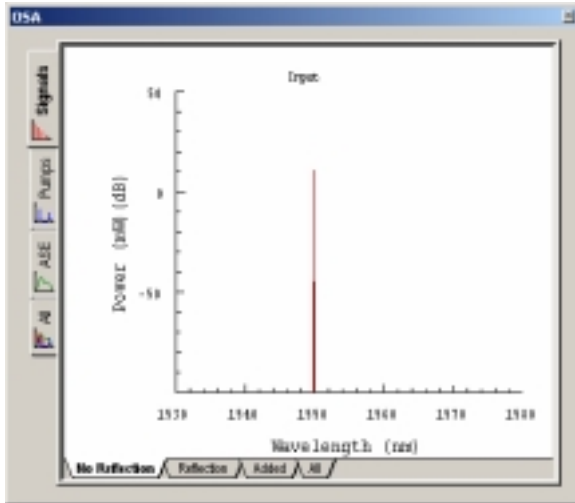


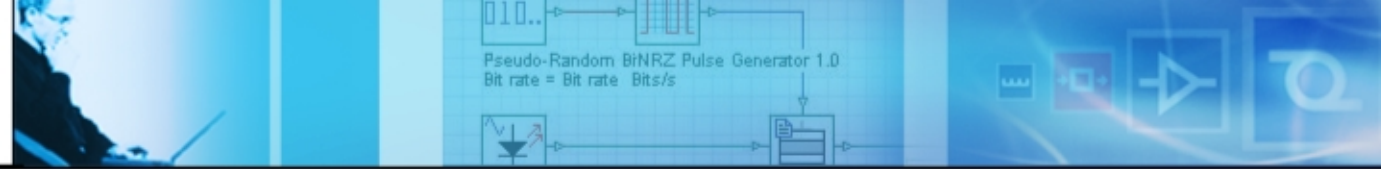
Ready

Layout | Parameter Sweeps | Views | Results | Report

Project1

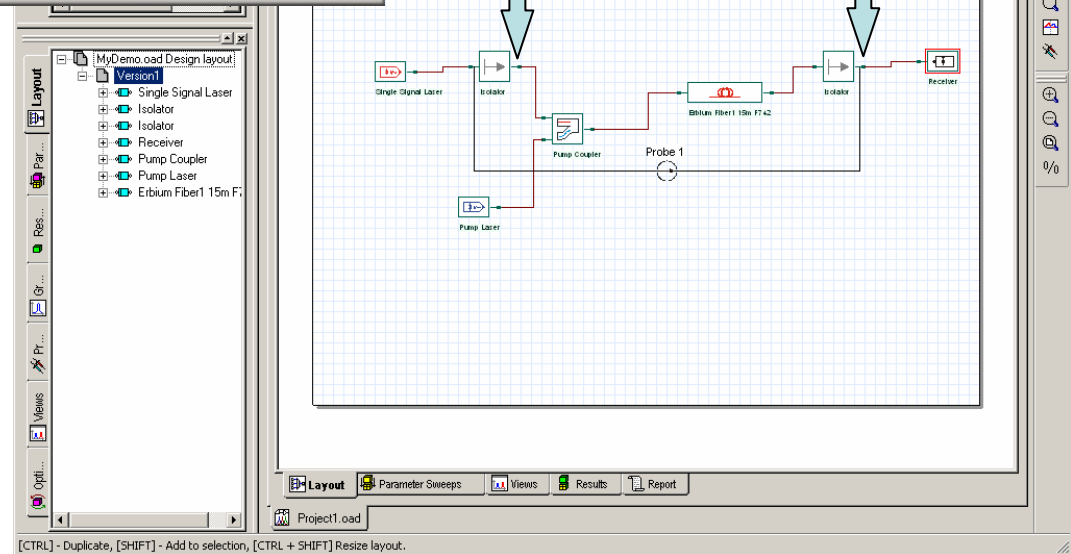
# Analyze the results - OSA

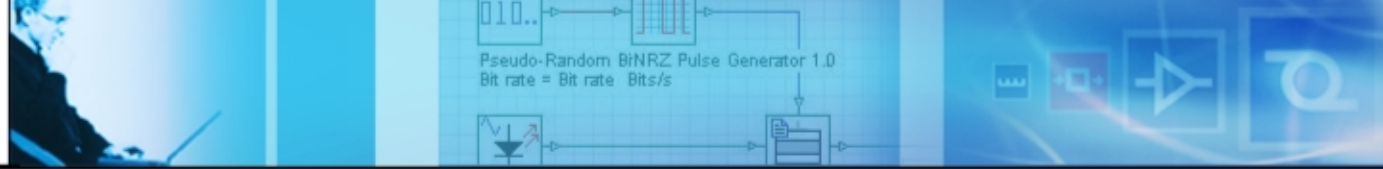




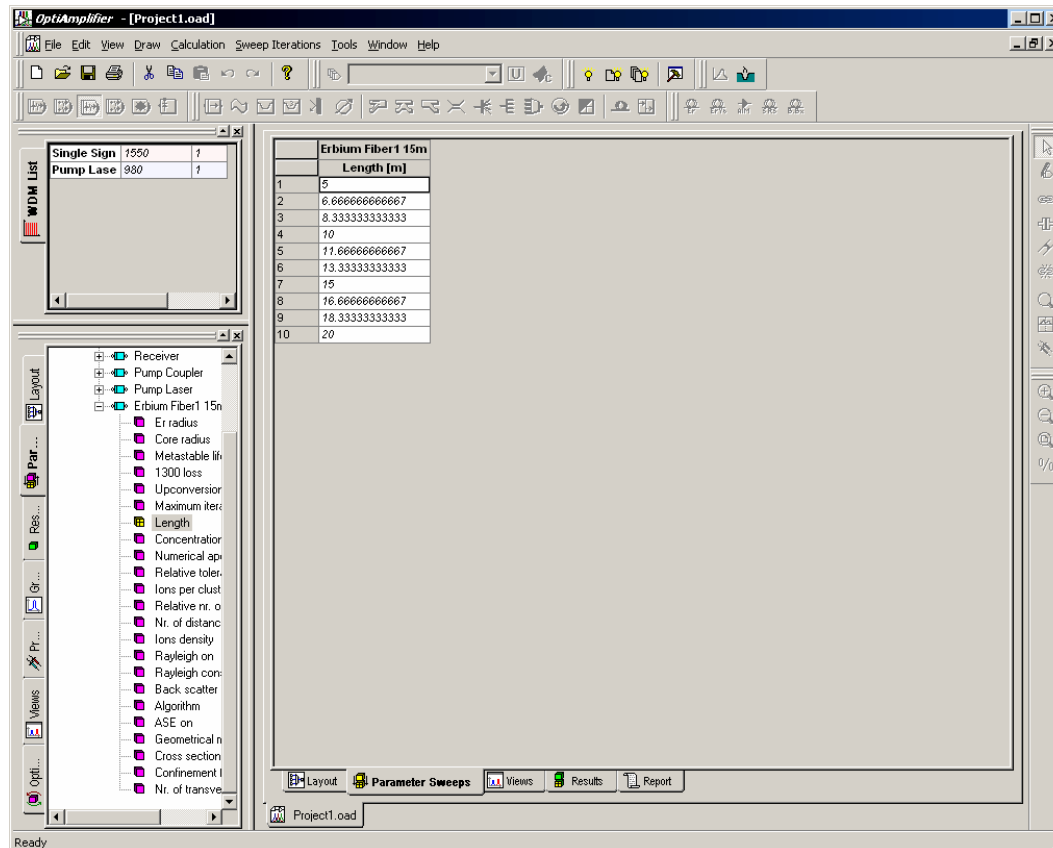
# Analyze the results - Probe

Output Power (dBm)	Reflected Output (dBm)	Gain (dB)	Transmitted Gain (dB)	Reflected Gain (dB)	Input OSNR (dB)	Output OSNR (dB)	Noise Figure (dB)	Input Return Loss (dB)
10.4079	-10.0664	30.5211	30.4879	+ INF	37.961	32.9710	4.98914	+ INF
99.4879	-99.6614	39.5211	39.4879	N/A	37.961	32.9710	4.98914	N/A
99.4879	-99.6614	39.5211	39.4879	N/A	37.961	32.9710	4.98914	N/A
0	0	0	0	N/A	0	0	0	N/A
99.4879	-99.6614	39.5211	39.4879	N/A	N/A	7.79645	0	N/A
-30.0942	- INF	+ INF	+ INF	+ INF				+ INF
-36.6942	N/A	N/A	N/A	N/A				N/A
-36.6942	N/A	N/A	N/A	N/A				N/A
0	N/A	N/A	N/A	N/A				N/A
-36.6942	N/A	N/A	N/A	N/A				N/A
2.37693	-6.39758	N/A	N/A	N/A				N/A
-47.138	-91.1367	N/A	N/A	N/A				N/A
-9.76984	-47.1958	N/A	N/A	N/A				N/A
37.5722	73.9416	N/A	N/A	N/A				N/A
-47.308	-91.1367	+ INF	+ INF	+ INF				+ INF
-47.2065	-90.7147	+ INF	+ INF	+ INF				+ INF
-47.0625	-90.2246	+ INF	+ INF	+ INF				+ INF





# Optimize Amplifier Parameters



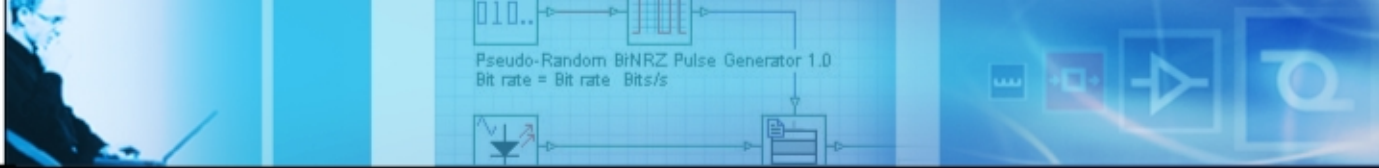
The screenshot shows the Optiwave software interface for a project named 'Project1.load'. The interface includes a menu bar (File, Edit, View, Draw, Calculation, Sweep Iterations, Tools, Window, Help), a toolbar, and several panels. On the left, there is a 'WDM List' panel with a table:

Single Sign	1550	?
Pump Laser	980	?

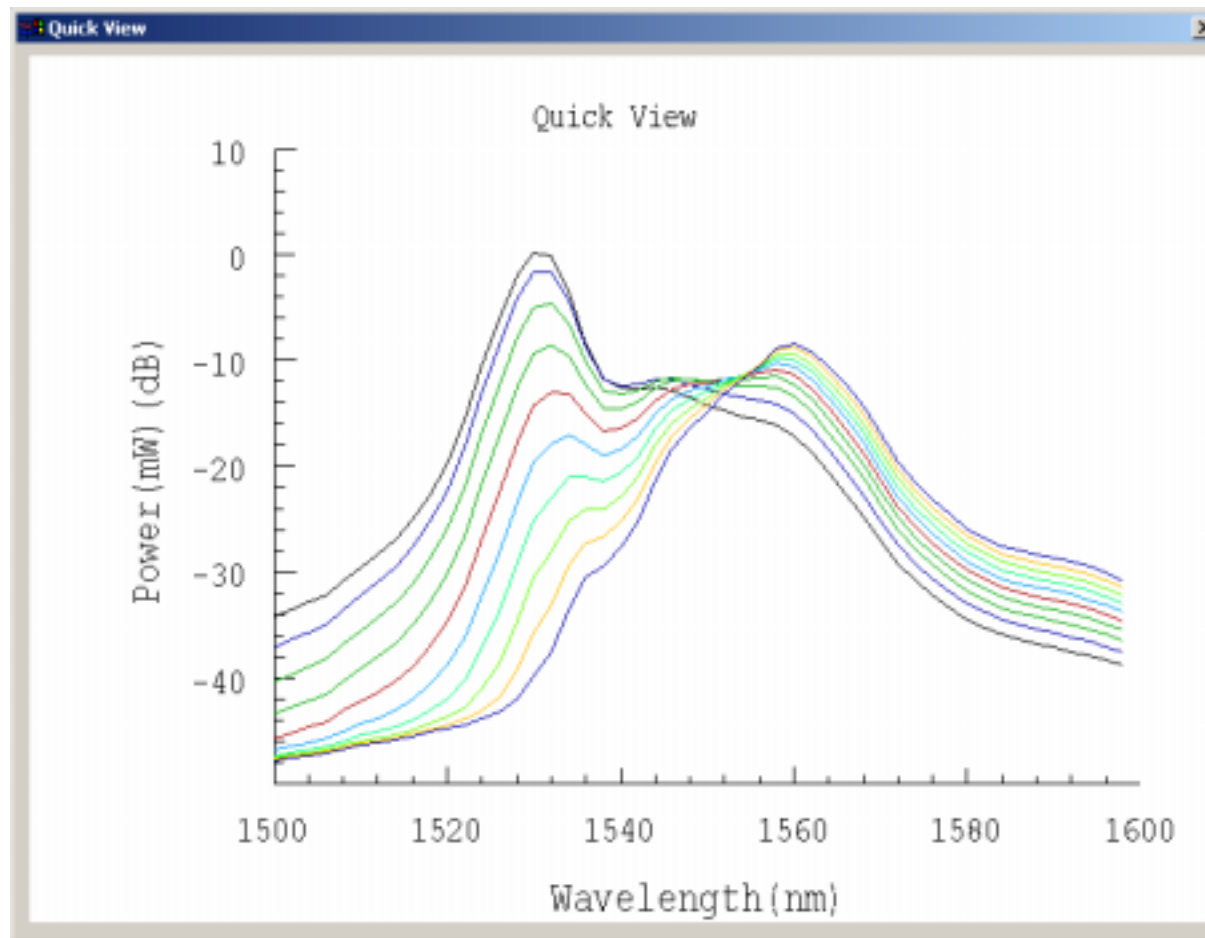
Below the WDM List is a 'Layout' panel showing a tree view of components: Receiver, Pump Coupler, Pump Laser, and Erbium Fiber1 15m. Under 'Erbium Fiber1 15m', the 'Length' parameter is highlighted. At the bottom left, there are buttons for 'Par...', 'Res...', 'Gr...', 'Pt...', 'Views', and 'Opti...'. The main workspace displays a table for 'Erbium Fiber1 15m' with the following data:

Erbium Fiber1 15m	
	Length [m]
1	5
2	6.66666666666667
3	8.33333333333333
4	10
5	11.6666666666667
6	13.3333333333333
7	15
8	16.6666666666667
9	18.3333333333333
10	20

At the bottom of the main workspace, there are tabs for 'Layout', 'Parameter Sweeps', 'Views', 'Results', and 'Report'. The 'Parameter Sweeps' tab is active. The status bar at the bottom left shows 'Project1.load' and 'Ready'.

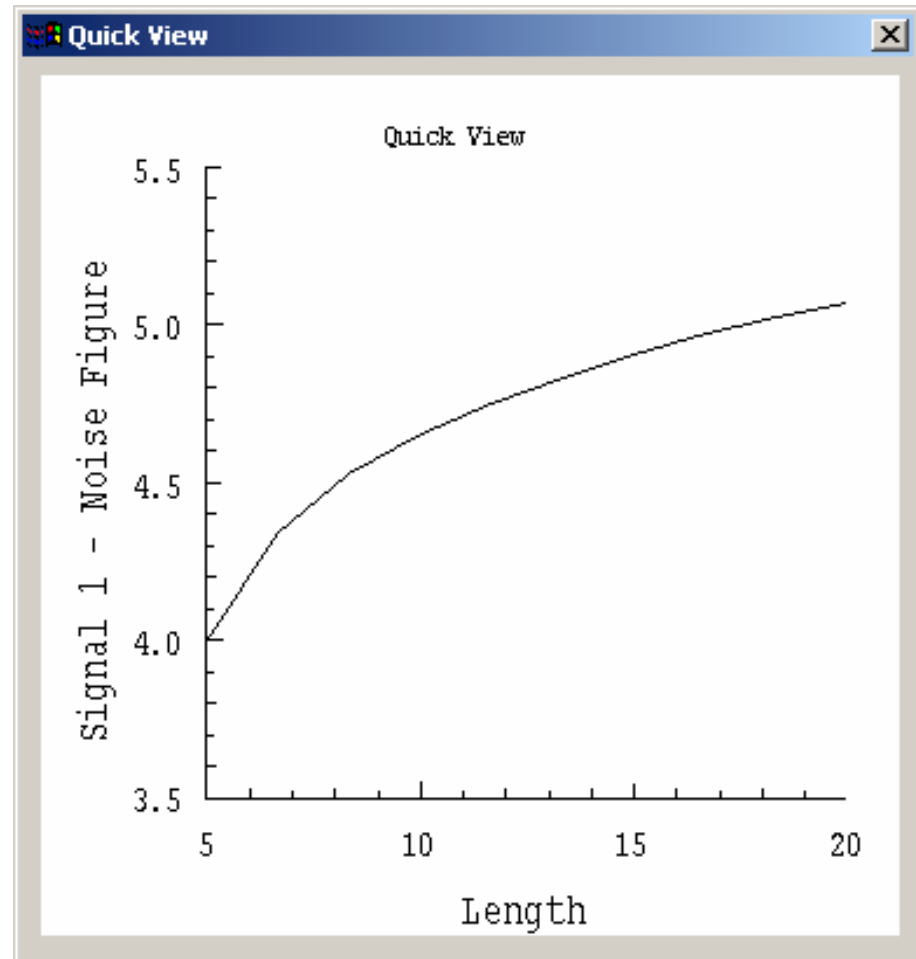
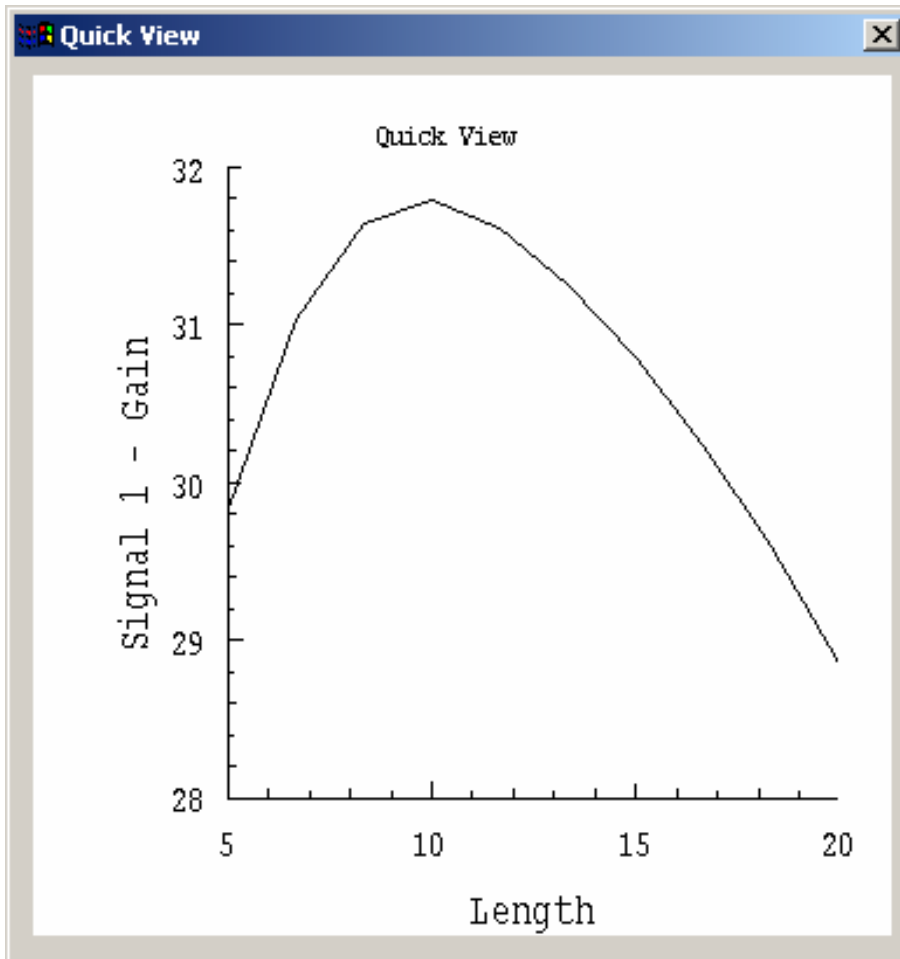


# Analyze the Results

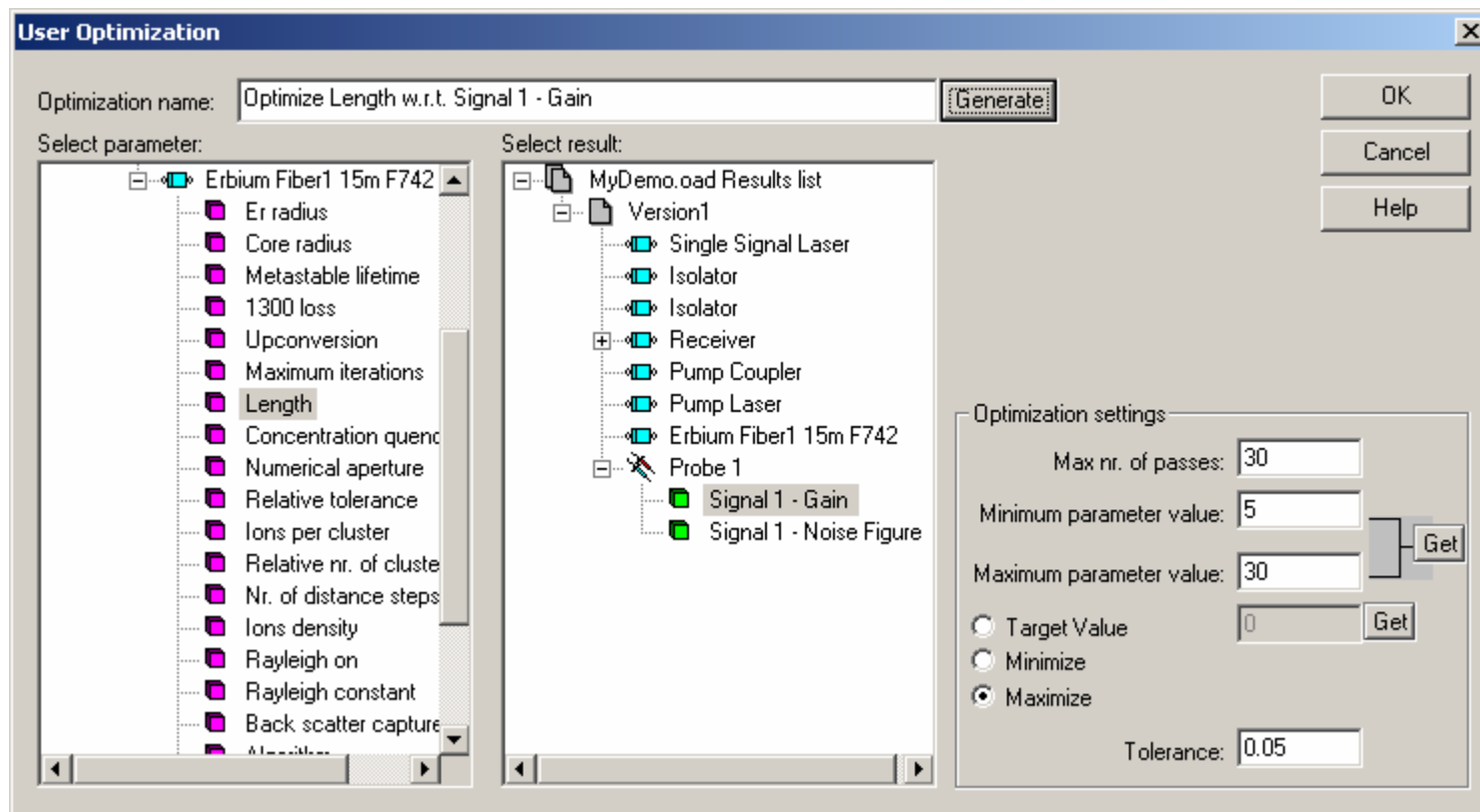


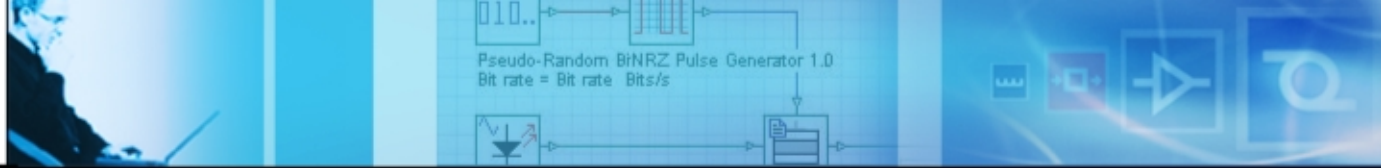


# Analyze the Results

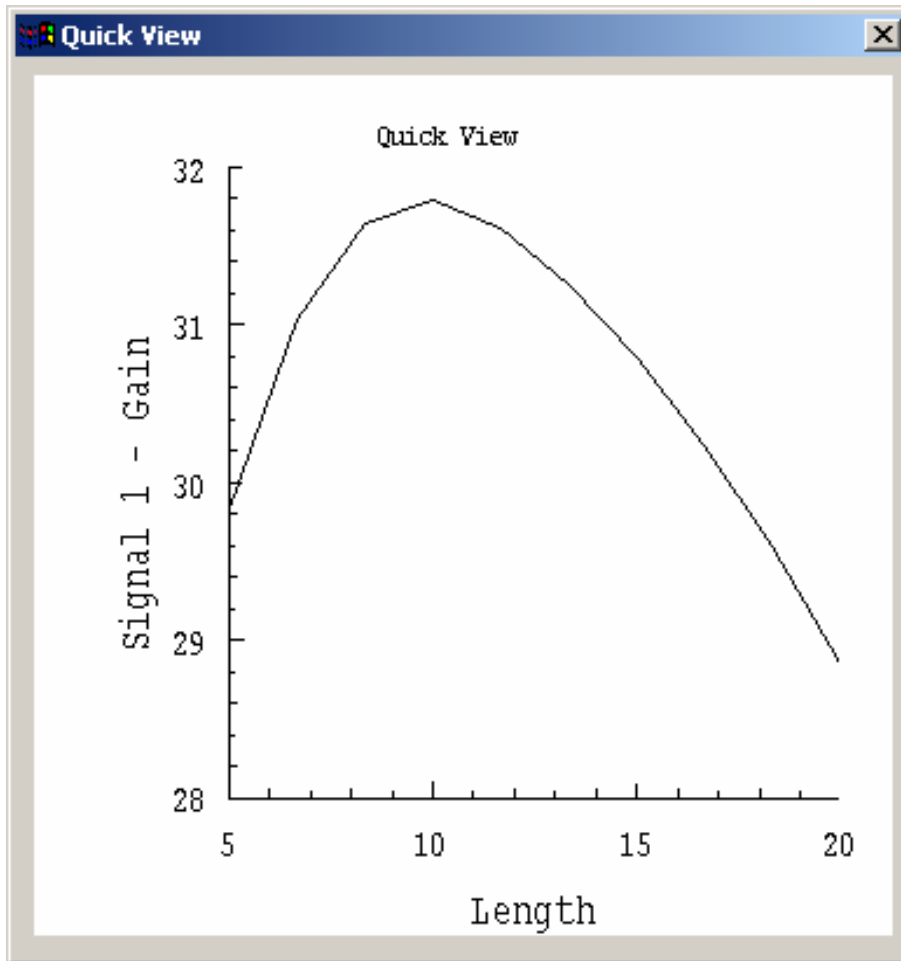


# Automatic Optimizations

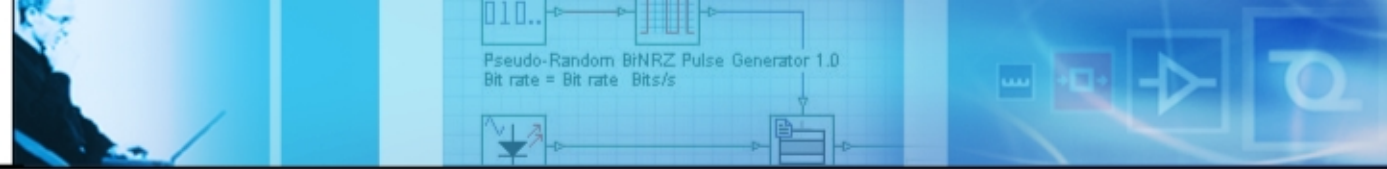




# Automatic Optimizations



Max at 9.72 m



# Comparing Results with Measurements

