OptiSPICE

Laser Parameter Extractor Manual

Laser Parameter Extractor Software for OptiSPICE

Version 5.2

OptiSPICE

Laser Parameter Extractor Manual

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Disclaimer

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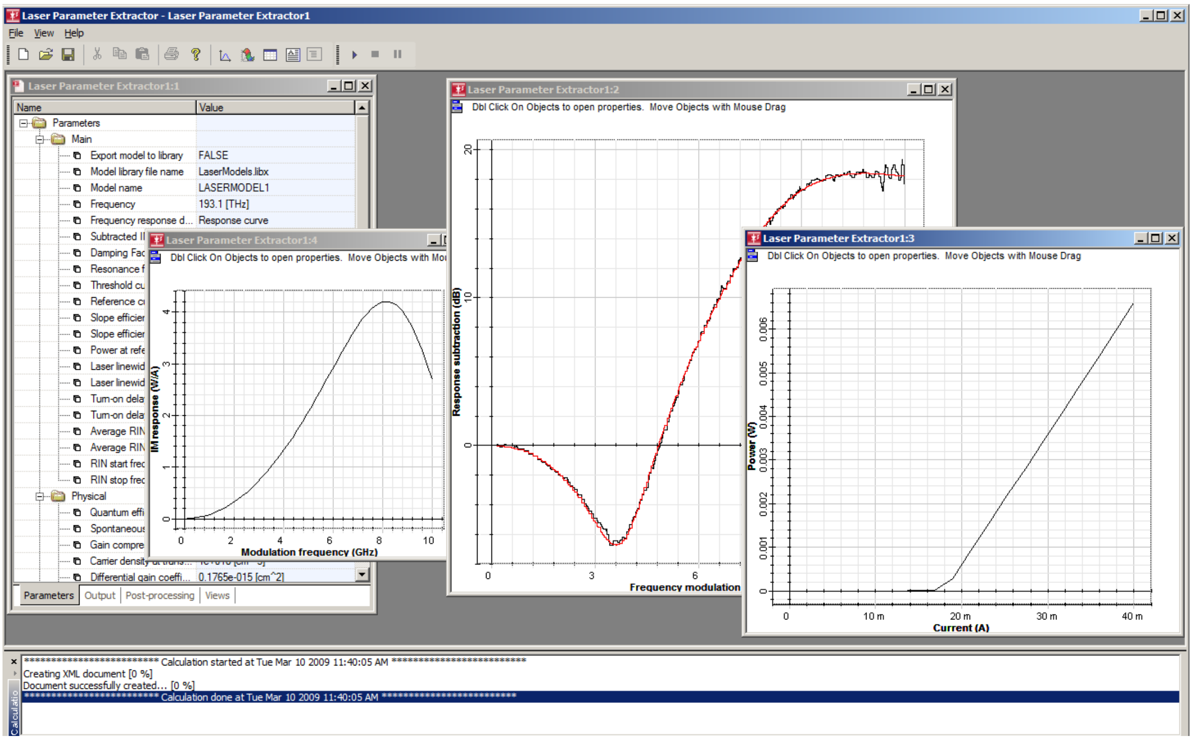
Introduction

The Laser Parameter Extractor is a software tool that enables parameter extraction for simulation of semiconductor lasers. Laser Parameter Extractor capabilities are derived from Optiwave's software, OptiSystem.

Laser Parameter Extractor generates a set of parameters for a laser rate equation numerical model using measured parameters defined by the user. The set of physical parameters generated are based in the well known laser rate equation modeling for single-mode semiconductor laser. OptiSPICE laser model uses these parameters set to simulate the attributes of the laser.

Figure 1 Laser Parameter Extractor GUI



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Main features

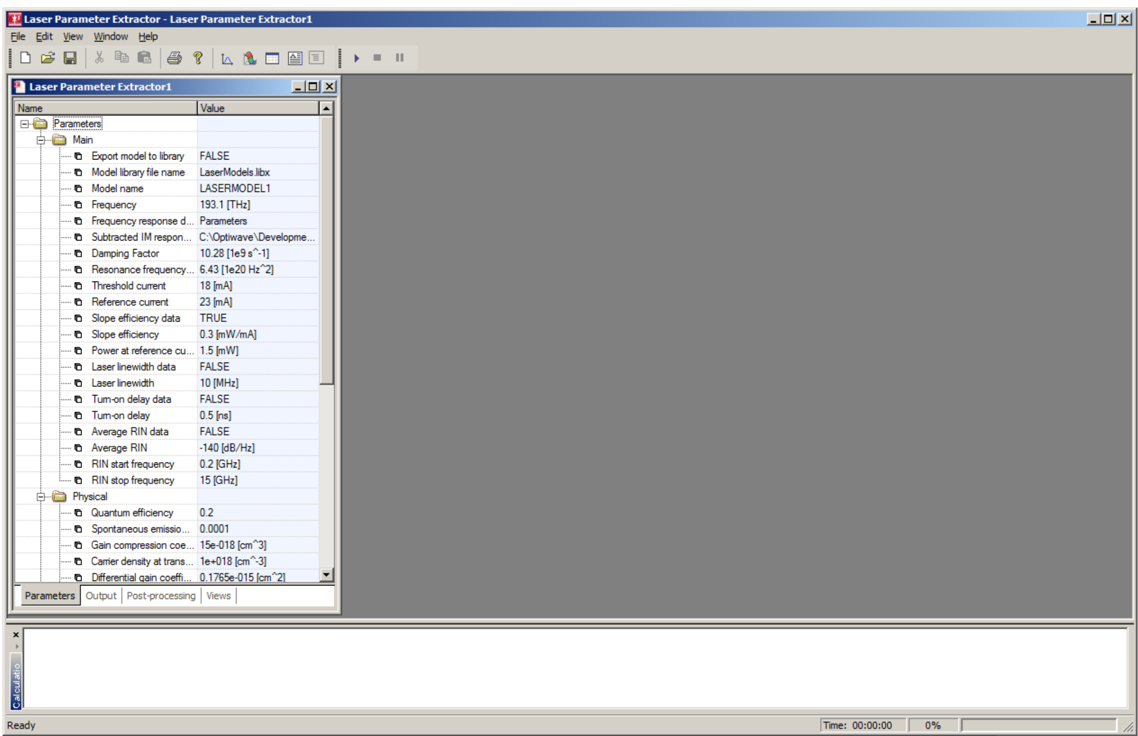
The main features of the Laser Parameter Extractor include:

Feature	Description
Graphical user interface	A comprehensive Graphical User Interface (GUI) controls the laser input parameters, output results, presentation graphics and post-processing.
Numerical engine	Accurate parameter extraction of lasers is based on minimizing the sum of squared errors between measured values and calculated values from the rate equation parameters.
Visualization capabilities	Powerful & intuitive result management allows users to graph almost any set of results available in design. Results are grouped into resizable, moveable views that supports text, tables, 2D and 3D graphs.
Post-Processing	A waveform calculators that uses standard Microsoft VBScript allows for unparalleled capability and flexibility to analyze simulation results.

Laser Parameter Extractor GUI

When you open the Laser Parameter Extractor, the application looks like Figure 1.

Figure 1   Laser Parameter Extractor graphical user interface (GUI)



Main parts of the GUI

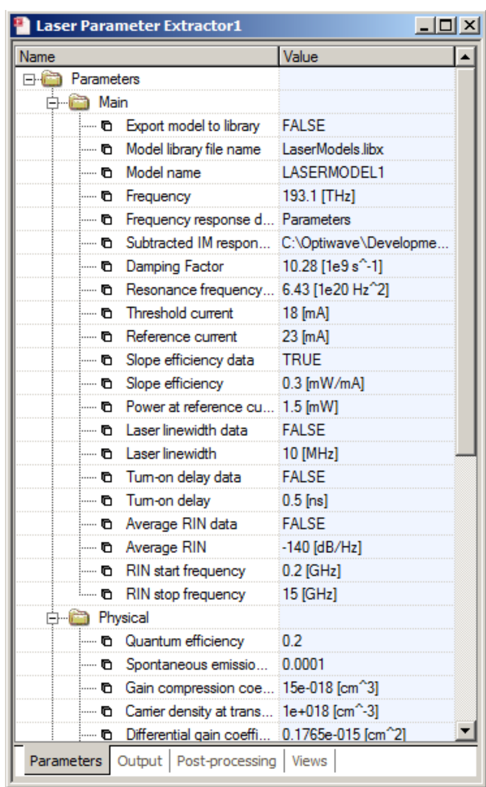
The Laser Parameter Extractor GUI contains the following main windows:

- Project Browser
    - Parameters tab
    - Output tab
    - Post-processing tab
    - Views tab
- Calculator
- Calculation Output
- Views
- Status bar
- Menu bar

Project Browser

Project browser allows the user to organize the project to achieve results more efficiently, and navigate through the current project, access parameters, results and views.(see Figure 2).

Figure 2 Project browser (Parameters tab)



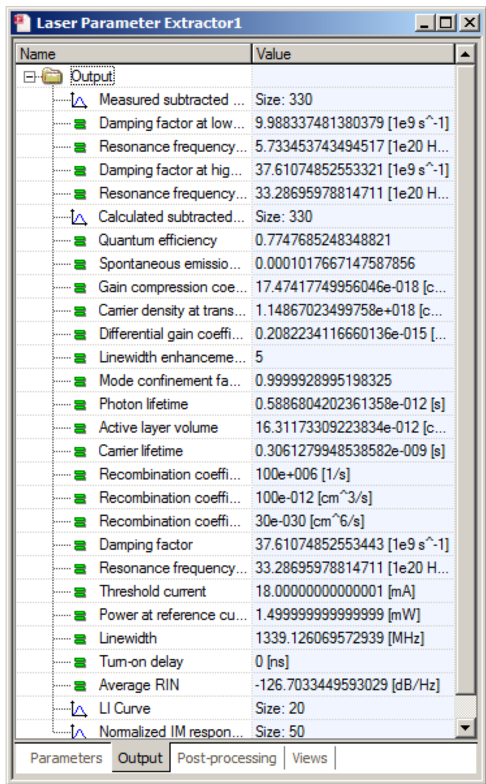
Parameters tab

Lists the properties of the current project. Users can access the parameter editor by double-clicking on any parameter in the list.

Output tab

Displays the results of the calculation (see Figure 3). User can drag-and-drop results into views or simply double-click on any result in order to launch the default view for a given result.

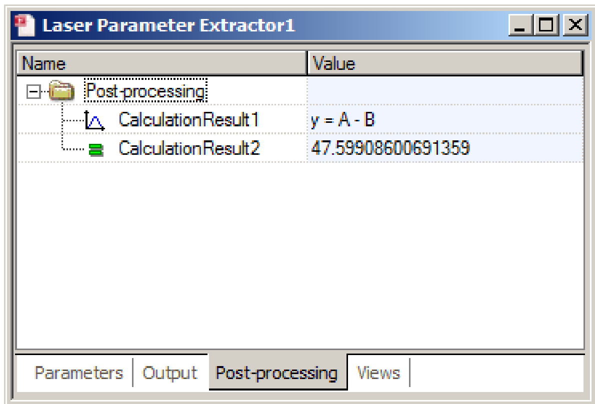
Figure 3 Project browser (Output tab)



Post-processing tab

Displays the post-processed results from the calculator (see Figure 4). User can drag-and-drop post-processed results into views or simply double-click on any post-processed result in order to launch the default view.

Figure 4 Project browser (Post-processing tab)

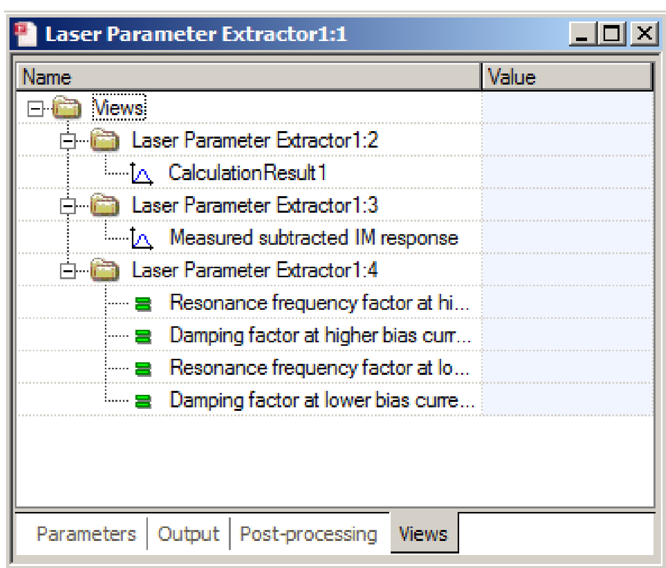


Views tab

Post-processing tab

Displays a list of views that represent active windows containing and displaying results (see Figure 5).

Figure 5 Project browser (Views tab)

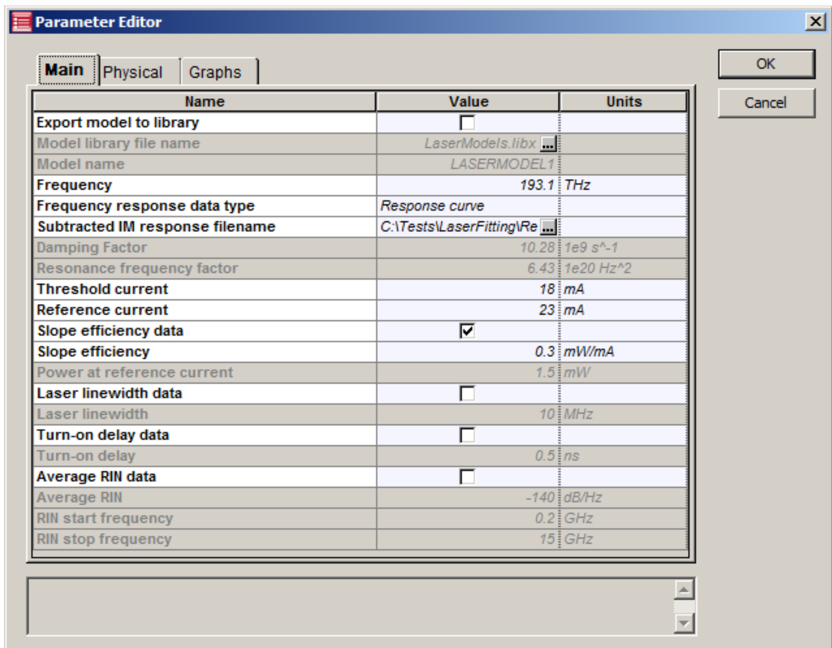


Parameter Editor

Double clicking on any parameter in the Project Browser will open the **Parameter Editor** (see Figure 6). The Parameter Editor allows you to view the list of global parameters of the active project.

Note: Please refer to the Technical Background for the description of the parameters listed in the editor.

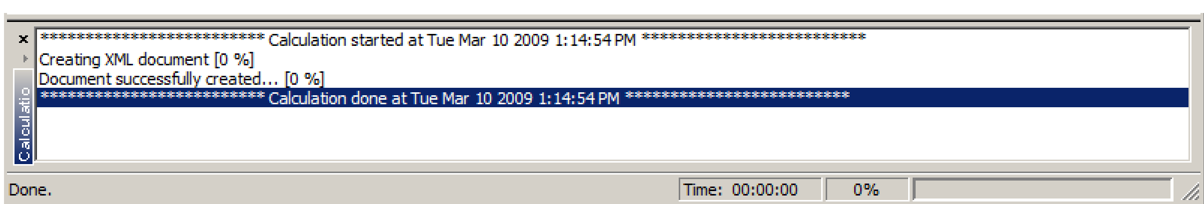
Figure 6 Parameter Editor control



Calculation Output

Information regarding the progress of the calculation is displayed in the Calculation output (see Figure 7).

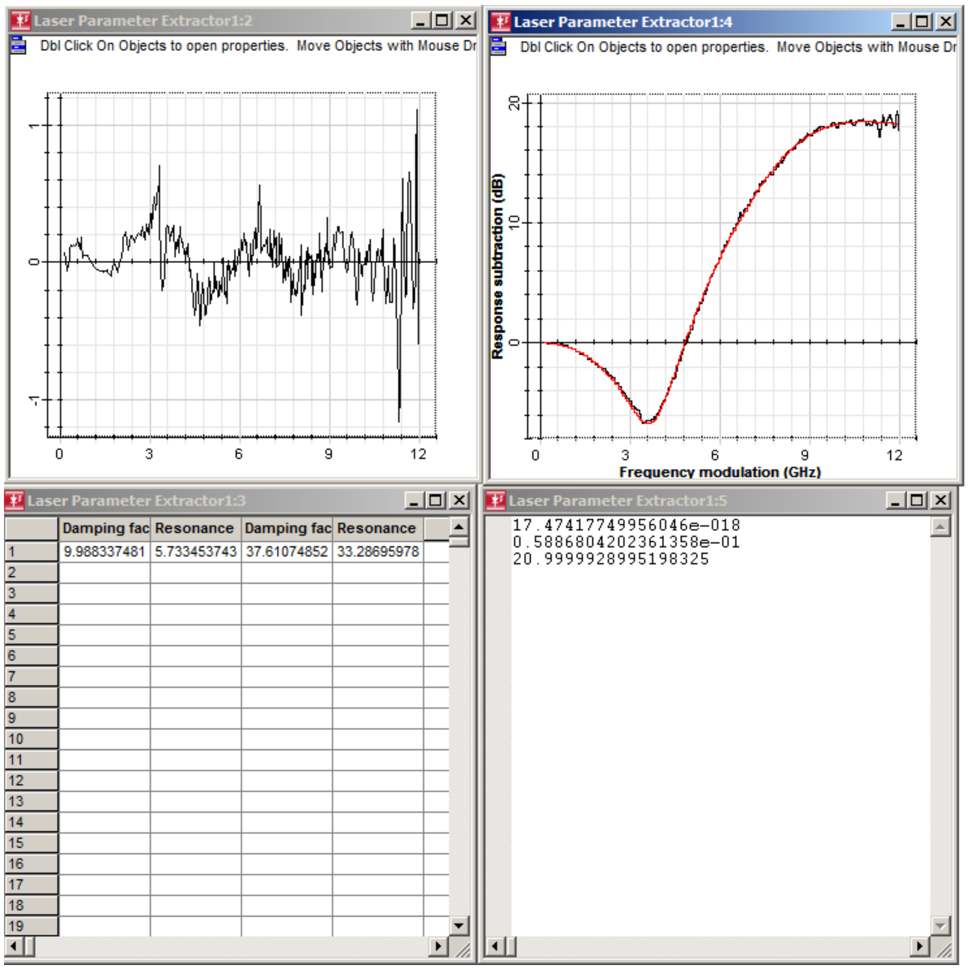
Figure 7 Calculation output



Views

Views are windows that contain results from calculation or post-processing (see Figure 8). They display 2D and 3D graphs, tables and text. A user can create an empty view by clicking in one of the toolbar buttons such as *Create 2D Graph View*, *Create 3D Graph View, Create Grid View* or *Create Text View*. Alternatively, by double-clicking on a result, a view will be automatically created or by selecting a result and clicking on the context menu (right-click) and selecting *View*.

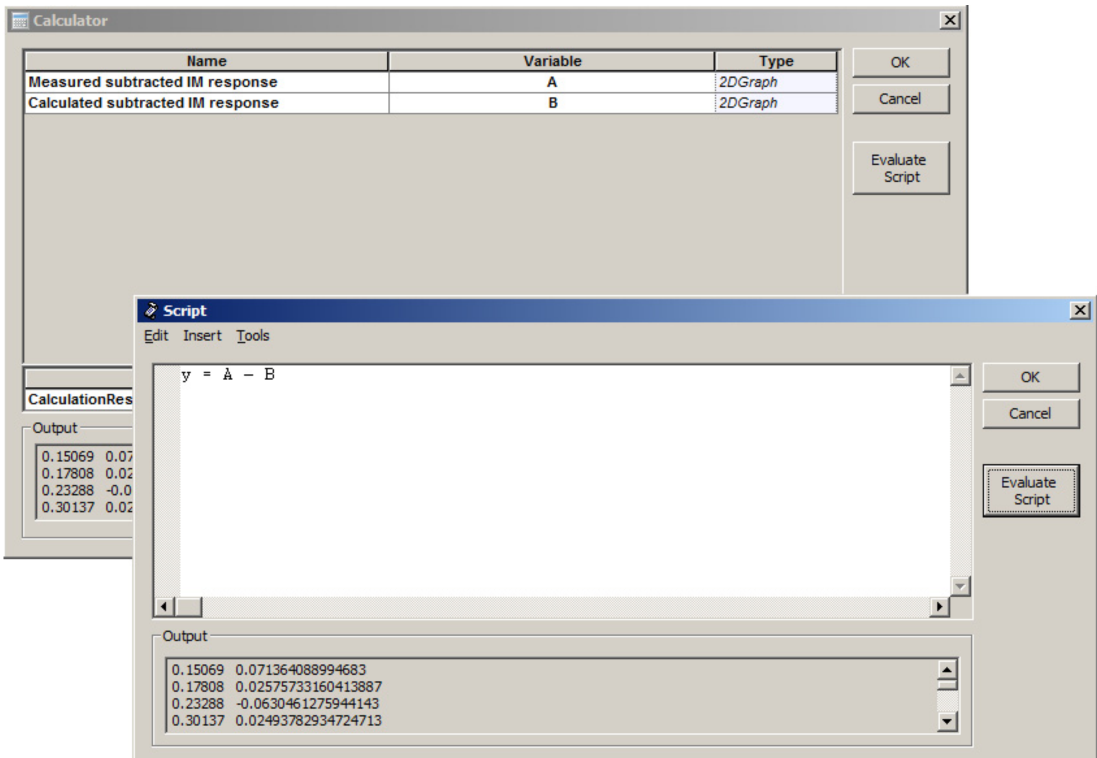
Figure 8 Multiple views



Calculator

The **Calculator** control allows you to operate on the output results to create new results and graphs. By selecting one or more results or 2D graphs the user can select the Calculator on the context menu (right-click). In order to create new results the user provides a script (Microsoft VBScript Language) that operates on the available variables - the output results MUST be provided to the Y variable.

Figure 9 Calculator



Status bar

Displays useful hints about using the Laser Parameter Extractor, the time and progress of the calculation (see Figure 10).

Figure 10 Status bar

Menu bar

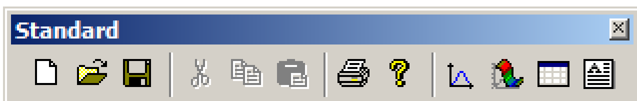
Contains the menus that are available in the Laser Parameter Extractor (see Figure 11). Many of these menu items are also available as buttons on the toolbars or from other lists.

Figure 11 Menu bar

Toolbars

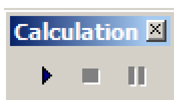
You can select the toolbars that you want to have available in the main layout window. The toolbar options include:

Standard



Contains the buttons to perform all typical windows application actions, in addition to create views options.

Calculation

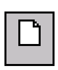
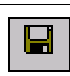


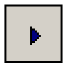
Calculate, pause or stop the project calculation.

Menus and buttons

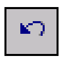
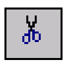
This section describes the menus and buttons available in the Laser Parameter Extractor.

File menu

File menu item	Toolbar button	Description
New (Ctrl+N)		Create a new project.
Open (Ctrl+O)		Open an existing project. Select the project from the **Open** dialog box.
Close		Close the active (current) project. You are prompted to save changes.
Save (Ctrl+S)		Save the active (current) project under the current name in the default location.
Save As		Save the active (current) project with a different name and in a location that you select.
Print (Ctrl+P)		Print the active (current) project.
Print Setup		Set up the printer, page size, orientation, and other printing options.

File menu item	Toolbar button	Description
Print Preview		Preview the active (current) project.
Calculate (Ctrl+F5)		Calculate the active (current) project.
Recent files		List the most recent files that you worked on.
Exit		Exit the application. You are prompted to save changes to the project.

Edit menu

Edit menu item	Toolbar button	Description
Undo (Ctrl+Z)		Undo the last change made in the active (current) layout. You can undo all actions until the last saved operation.
Cut (Ctrl+X)		Remove all selected objects and place them on the clipboard.
Copy (Ctrl+C)		Copy selected objects to the clipboard. The selected objects remain in the active project.
Paste (Ctrl+V)		Copy objects from the clipboard and paste them in a user-defined location—the same layout, a new subsystem, or a new layout.

View menu

View menu item	Toolbar button	Description
Toolbars		
Standard		Select to display the **Standard** toolbar.
Calculation		Select to display the **Calculation** toolbar.
Status Bar		Select to display the **Status Bar**.

Window menu

Window menu item	Toolbar button	Description
Cascade		Arranges all open views in a cascading format.
Tile		Arranges all open views in a tile format.
Arrange icons		Lines up minimized views at the bottom of the application.

Help menu

Help menu item	Description
About Laser Parameter Extractor	Provides information about Optiwave Systems inc.—mailing address, telephone and fax numbers, E-mail address, and URL.

Quick Start

This section describes how to run a project, edit parameters, and obtain results.

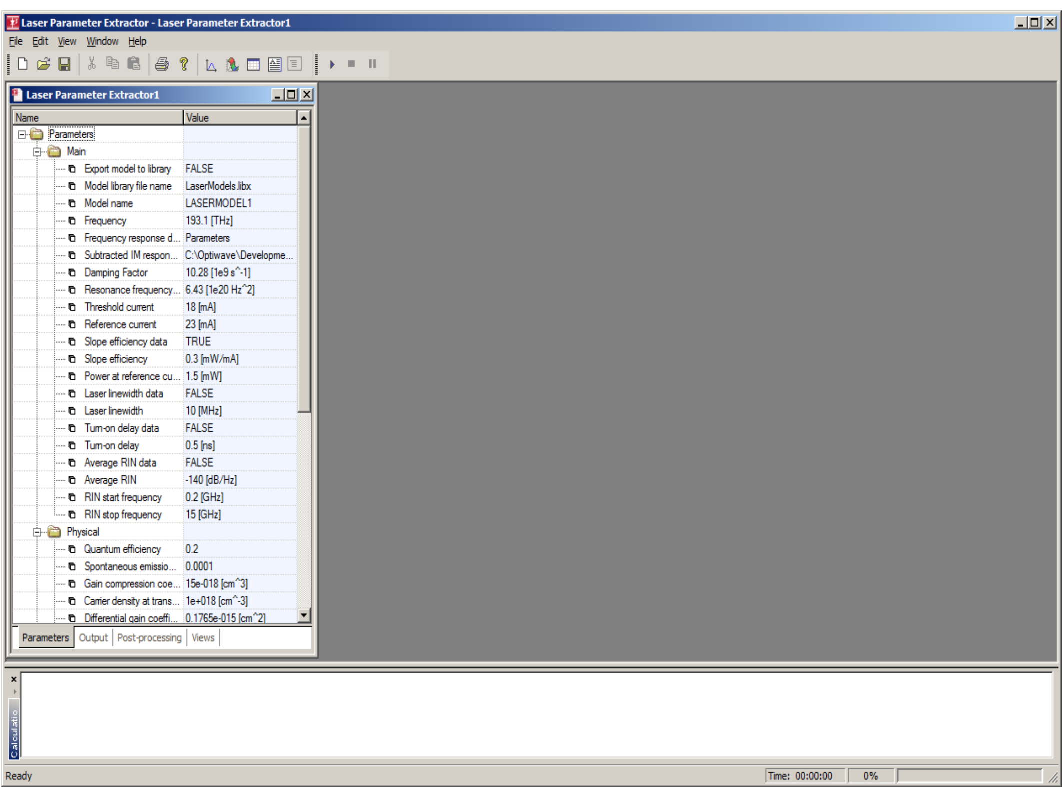
Starting Laser Parameter Extractor

To start **Laser Parameter Extractor**, perform the following action.

Action

- From the **Start** menu, select **Programs** > **Optiwave Software**> **OptiSPICE 1> Laser Parameter Extractor**.
  Laser Parameter Extractor loads and the graphical user interface appears (see Figure 1).

Figure 1 Laser Parameter Extractor graphical user interface (GUI)



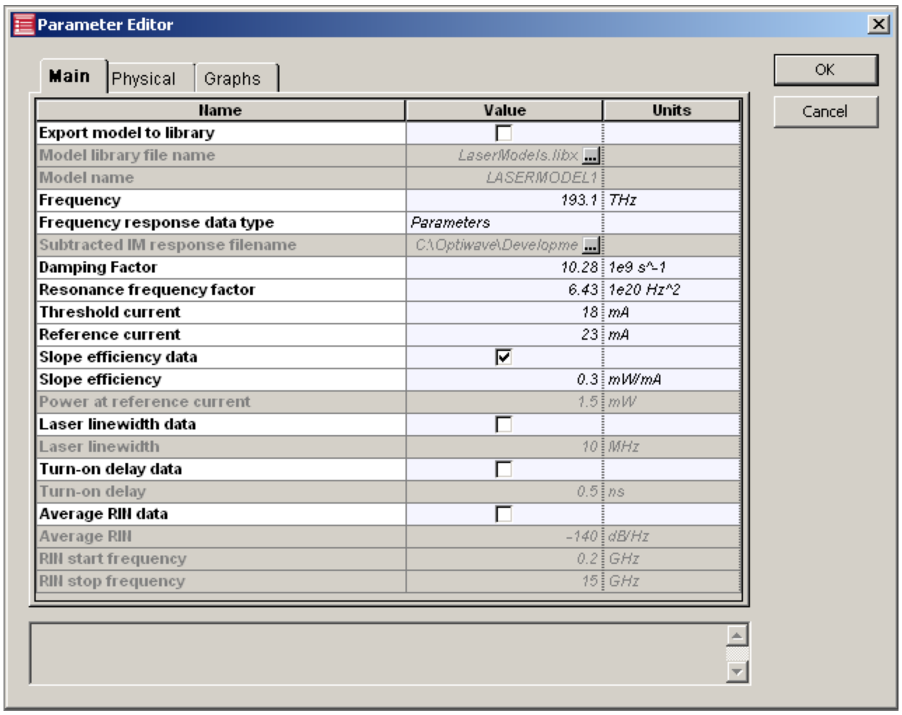
Viewing and editing parameters

To view and edit the project parameters perform the following action.

Action

- In the **Project Browser**, double-click on any parameter in the Parameters tab to view and edit the parameters for the project.
  *The **Parameter Editor** (see Figure 2) dialog box appears.*

Figure 2 Parameter Editor



Parameters are organized by categories. **Laser Parameter Extractor** has three categories, each represented by a tab in the dialog box:

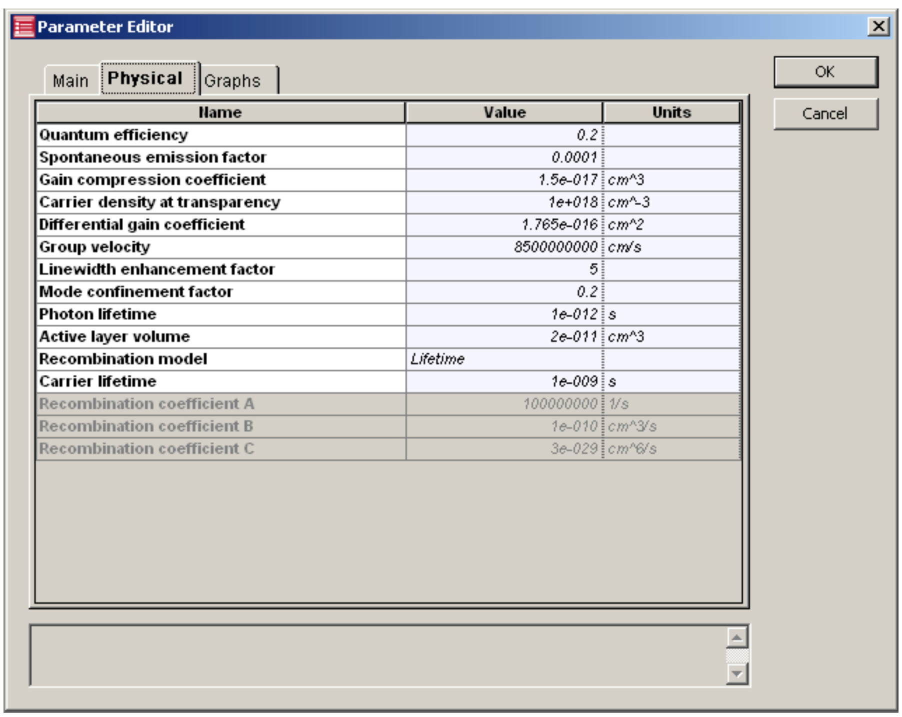
- Main
- Physical
- Graphs

Each category has a set of parameters. Parameters have the following properties:

- Name
- Value
- Unit

The first category is **Main**. By default, Laser Parameter Extractor will use a the *Damping factor* (10.28×10^9 s^{-1}) and *resonance frequency factor* (6.43×10^{20} Hz^2) parameters for the laser frequence response, *threshold current* of 18 mA, *reference current* of 23 mA and *slope efficiency* of 0.3 mW/mA. The second category is **Physical**, and it defines the intial estimation for the laser rate equation paramaters optimization process (see Figure 3). For a detailed description of each parameter please refer to Technical Background.

Figure 3 Parameter physical.

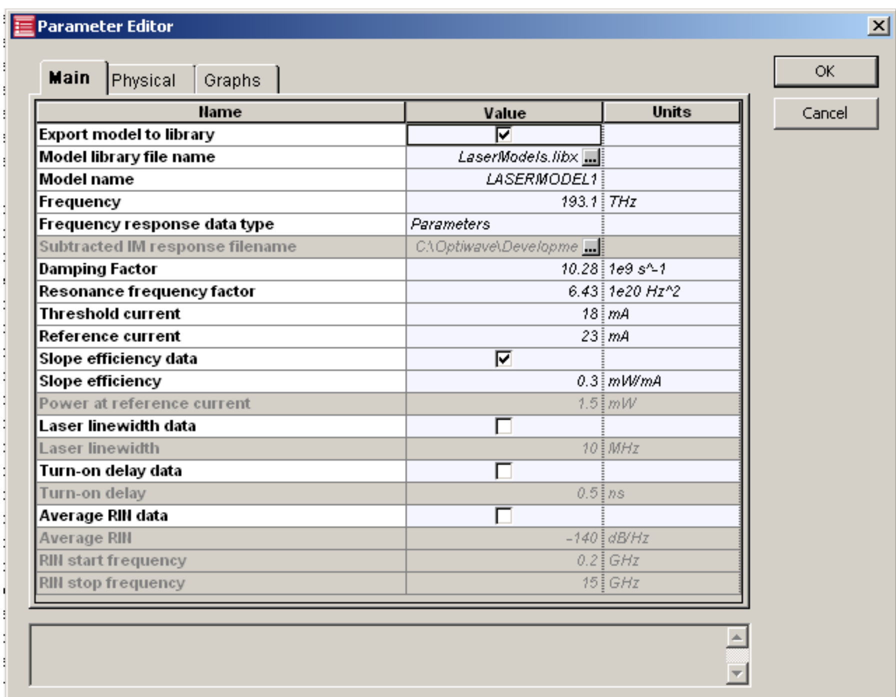


Parameter settings to create a laser library for OptiSPICE

To create a laser library for OptiSPICE perform the following actions.

Step	Action
1	In the **Project Browser**, double-click on any parameter in the Parameters tab to view and edit the parameters for the project. *The **Parameter Editor** (see Figure 2) dialog box appears.*
2	Enable *Export model to library* by selecting the box inside the value box.
3	Once the *Export model to library* parameter has been set to True, the *Model library file name* and *Model name* parameters will be available for editing. Set the Library file name - LaserModels.libx is the root name for the library and list of files generated by the Laser Parameter Extractor (see Figure 4).
4	Set the *Model name* parameter, the file destination generated by the Laser Parameter Extractor .LASERMODEL1 is the default value name generated.
5	Click on OK

Figure 4 Settings to create a laser library.



Running a simulation

To run a simulation and create a library file for OptiSPICE, perform the following procedure.

Step	Action
1	In the Calculation toolbar, click on 'Play' (see Figure 6). *The* ***Calculations*** *starts (see Figure 6).*

Figure 5 Calculation toolbar

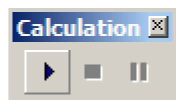
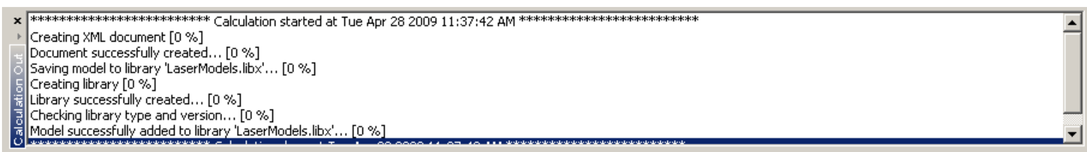


Figure 6 Calculation Output



At the end of the calculation the output tab will contain the results of the simulation.

Visualizing results

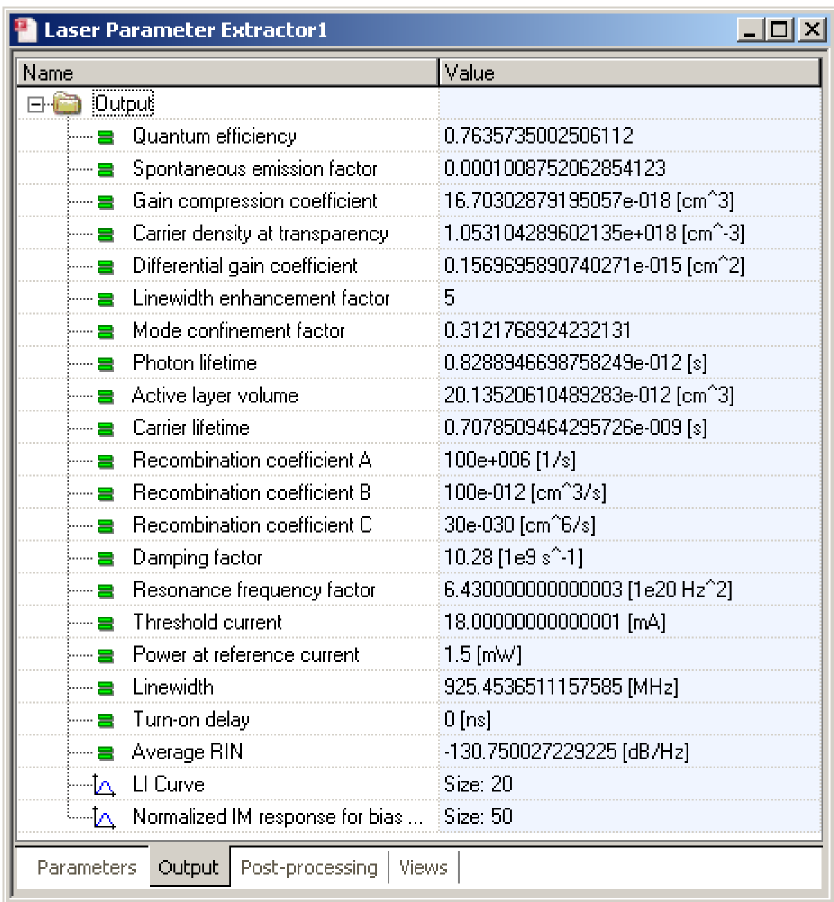
To view the results from the calculation, perform the following action.

Action

1 In the **Project Browser**, click on the Output tab to view the results for the project (see Figure 7)
The list of results for each optimization processes includes single values (laser rate equation parameters and calculated results based on these parameters), and 2D Graphs (LI Curve and Normalized IM response for bias current)

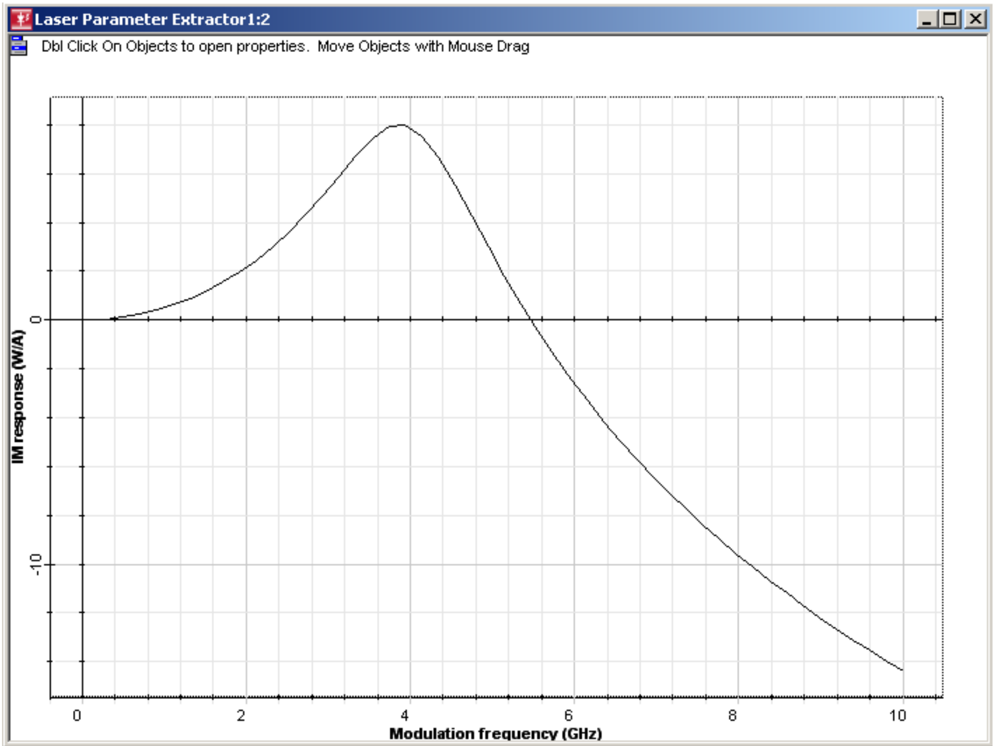
2 Double-click on *Normalized IM response* result.
The 2D Graph view appears (see Figure 8).

Figure 7 Output results



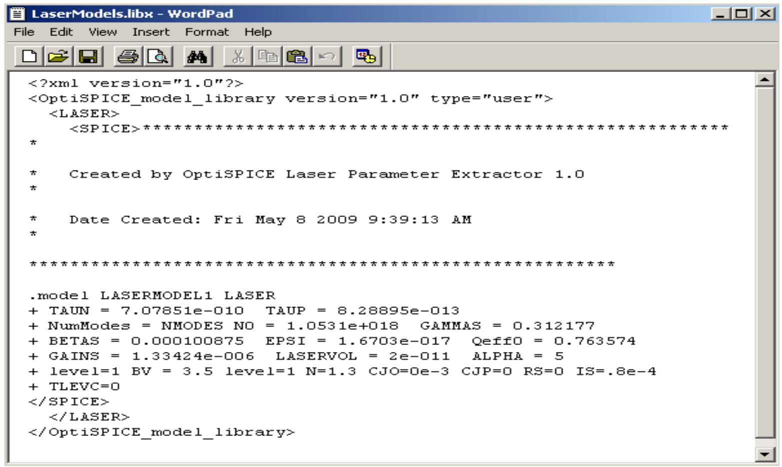
Name	Value
Output	
Quantum efficiency	0.7635735002506112
Spontaneous emission factor	0.000100875206285412 3
Gain compression coefficient	16.70302879195057e-018 [cm^3]
Carrier density at transparency	1.053104289602135e+018 [cm^-3]
Differential gain coefficient	0.1569695890740271e-015 [cm^2]
Linewidth enhancement factor	5
Mode confinement factor	0.3121768924232131
Photon lifetime	0.8288946698758249e-012 [s]
Active layer volume	20.13520610489283e-012 [cm^3]
Carrier lifetime	0.7078509464295726e-009 [s]
Recombination coefficient A	100e+006 [1/s]
Recombination coefficient B	100e-012 [cm^3/s]
Recombination coefficient C	30e-030 [cm^6/s]
Damping factor	10.28 [1e9 s^-1]
Resonance frequency factor	6.430000000000003 [1e20 Hz^2]
Threshold current	18.00000000000001 [mA]
Power at reference current	1.5 [mW]
Linewidth	925.4536511157585 [MHz]
Turn-on delay	0 [ns]
Average RIN	-130.750027229225 [dB/Hz]
LI Curve	Size: 20
Normalized IM response for bias ...	Size: 50

Figure 8 Normalized IM response



The contents of LaserModels.libx are depicted in Figure 9. LaserModels.libx contains the list of laser models generated after the calculation. The Laser model contains the information (laser rate equation parameters) generated by the LPE.

Figure 9   Contents of the file generated by the Laser Parameter Extractor.



```
<?xml version="1.0"?>
<OptiSPICE_model_library version="1.0" type="user">
  <LASER>
    <SPICE>**********************************************************
*

*   Created by OptiSPICE Laser Parameter Extractor 1.0
*

*   Date Created: Fri May 8 2009 9:39:13 AM
*

**********************************************************

.model LASERMODEL1 LASER
+ TAUN = 7.07851e-010  TAUP = 8.28895e-013
+ NumModes = NMODES NO = 1.0531e+018  GAMMAS = 0.312177
+ BETAS = 0.000100875  EPSI = 1.6703e-017  Qeff0 = 0.763574
+ GAINS = 1.33424e-006  LASERVOL = 2e-011  ALPHA = 5
+ level=1 BV = 3.5 level=1 N=1.3 CJO=0e-3 CJP=0 RS=0 IS=.8e-4
+ TLEVC=0
</SPICE>
  </LASER>
</OptiSPICE_model_library>
```

Saving the project and closing Laser Parameter Extractor

To save the project and close the Laser Parameter Extractor, perform the following procedure.

Step	Action
1	From the **File** menu, select **Save** or **Save As...**
2	From the **File** menu, select **Exit**. *Laser Parameter Extractor closes.*

Technical Background

Parameters

Main

Name and description	Default value	Default unit	Value range
Export model to library Defines whether to generate the library that contains the laser model attributes for OptiSPICE	False		False, True
Model Library file name The library file name containing the laser models	LaserModels.libx		
Model name Unique name for the laser model	LASERMODEL1		
Frequency Emission frequency	193.1	THz	[30, 3e5]
Frequency response data type Defines whether tthe frequence response data is defined by the damping factor and resonance frequency factor parameters or by the subtracted IM response curve	Parameters		Parameters, Response curve
Subtracted IM response file name File containning the subtracted IM response curve	IMResponse.dat		
Damping Factor The measured damping factor of the laser	10.28	1e9 s^-1	[0.0001, 1000]
Resonance frequency factor The measured defined resonance frequency factor	6.43	1e20 Hz^2	[0.001, 1000]

Name and description	Default value	Default unit	Value range
Threshold current The measured threshold current of the laser	18	mA	[0.001, 1000]
Reference current The reference current used to estimate the measured output power	23	mA	[0.001, 1000]
Slope efficiency data Defines whether to use slope efficiency or power to estimate the LI curve	True		False, True
Slope efficiency The measured slope efficiency of the laser	0.3	mW/mA	[0.001, 1000]
Power at reference current The laser power at the reference current	1.5	mW	[1e-10, 1000]
Laser linewidth data Determines whether the linewidth will be part of the parameter extraction procedure	False		False, True
Laser linewidth Specifies the laser linewidth for the steady-state condition	10	MHz	[0.1, 2000]
Turn-on delay data Determines whether the turn-on delay will be part of the parameter extraction procedure	False		False, True
Turn-on delay Specifies the laser turn-on delay	0.5	ns	[0.001, 2000]
Average RIN data Determines whether the average RIN in a specified bandwidth will be part of the parameter extraction procedure	False		False, True
Average RIN Specifies the average RIN value for the steady-state condition over the frequency bandwidth defined by the values of RIN start and stop.	-140	dB/Hz	[-500, -50]
RIN start frequency Specifies the initial frequency of the frequency range where the average RIN is calculated	0.2	GHz	[0.01, 30]
RIN stop frequency Specifies the final frequency of the frequency range where the average RIN is calculated	15	GHz	[0.01, 30]

Physical

Name and description	Default value	Default unit	Value range
Quantum efficiency	0.2	—	0, 1
Spontaneous emission factor	0.0001	—	1e-9, 0.1
Gain compression coefficient	1.5e-017	cm^3	1e-20, 1e-14
Carrier density at transparency	1e+018	cm^{-3}	0, 100e18
Differential gain coefficient	1.765e-016	cm^2	0, 1e-13
Group velocity	8.5e+009	cm/s	0, 100e9
Linewidth enhancement factor	5	—	0, 100
Mode confinement factor	0.2	—	0, 1
Photon lifetime	1e-012	s	0, 1000e-9
Active layer volume	2e-011	cm^3	0, 1e-3
Recombination model	Lifetime	—	Lifetime, Coefficients
Carrier lifetime	1e-009	s	0, 1000e-9
Recombination coefficient A Linear recombination coefficient	100000000	1/s	0, 1e15
Recombination coefficient B Bimolecular recombination coefficient	1e-10	cm^3/s	0, 1e-9
Recombination coefficient C Auger recombination coefficient	3e-029	cm^6/s	0, 1e-9

Graphs

Name and description	Default value	Units	Value range
Calculate graphs Defines whether to calculate graphs or not	True		True, False
Number of current points Number of points for the graph	20		[3, 1000]
Lower current Current lower limit for the graphs	0	mA	[0, 1000F]
Upper current Current upper limit for the graphs	40	mA	[0, 1000]

Name and description	Default value	Units	Value range
Number of frequency points Number of points for the graph	50		[3, 10000]
Lower frequency Frequency lower limit for the graphs	0.1	GHz	[0, 100]
Upper frequency Frequency upper limit for the graphs	10	GHz	[0, 100]

Technical Background

The laser parameter extractor tool extracts values of the rate equation parameters using measurements of the threshold current, optical power, resonance frequency, and damping factor to simulate a DFB laser.

Based on the results featured in [1], the values of the rate equation parameters are calculated in a way that parameters simultaneously yield the measured values of Y (*damping factor*), Z (*resonance frequency factor*), I_{th} (*threshold current*), and P (*Power bias*). The parameter extraction procedure is based on minimization of the sum of squared errors between the measured values of (Y, Z, I_{th}, P) and values calculated from rate equation parameters. The minimization is over the values of the rate equation parameters which are:

Damping factor

$$Y = g_0 \frac{\bar{S}}{(1+\varepsilon\cdot\bar{S})} + \frac{1}{\tau_n} - \Gamma\cdot g_0(\bar{N}-N_t)\frac{1}{(1+\varepsilon\cdot\bar{S})^2} + \frac{1}{\tau_p}$$

Resonance frequency factor

$$Z = g_0 \frac{\bar{S}}{(1+\varepsilon\cdot\bar{S})}\cdot\frac{1}{\tau_p} + (\beta-1)\cdot\Gamma\cdot\frac{g_0}{\tau_n}g_0(\bar{N}-N_t)\frac{1}{(1+\varepsilon\cdot\bar{S})^2} + \frac{1}{\tau_p\cdot\tau_n}$$

Threshold current

$$I_{th} = \frac{q\cdot V}{\tau_n}\cdot\frac{1+N_t\cdot\Gamma\cdot g_o\cdot\tau_p}{\Gamma\cdot g_o\cdot\tau_p}$$

Power bias

$$P = \frac{S\cdot V\cdot\eta_0\cdot h\cdot v}{2\cdot\Gamma\tau_p}$$

where g_o is the gain slope constant, $g_o = v_g \cdot a_o$

a_0	is the active layer coefficient
ε	is the gain compression factor
N_t	is the carrier density at transparency
β	is the fraction of spontaneous emission coupled into the lasing mode
Γ	is the mode confinement factor
η_0	is the differential quantum efficiency
V	is the active layer volume
τ_p	is the photon lifetime
τ_n	is the electron lifetime
$\bar{N} and \bar{S}$	are the steady-state values of the carrier and photon densities corresponding to the bias current of the laser
v	is the unmodulated optical frequency
v_g	is the group velocity
h	is the Planck's constant

The minimization routine finds a local minimum for the equation

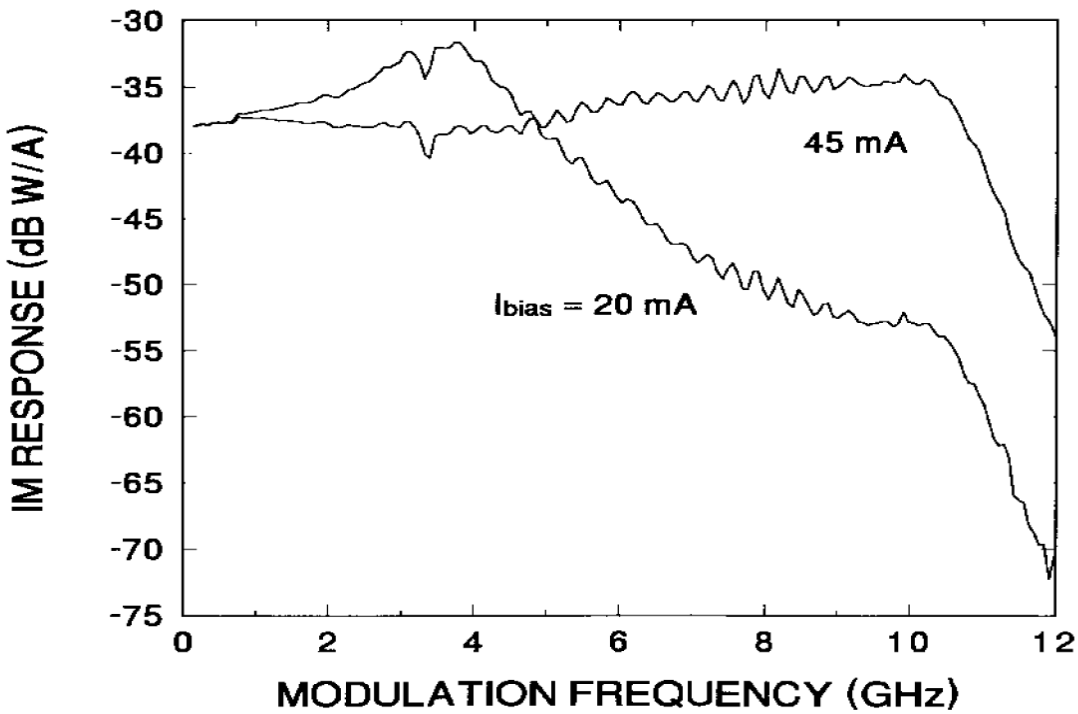
$$Func = (Y_{mea} - Y_{cal})^2 + (z_{mea} - z_{cal})^2 + (P_{mea} - P_{cal})^2 + (I_{mea} - I_{cal})^2$$

where $(Y_{mea}, Z_{mea}, P_{mea}, I_{mea})$ are the measured values and $(Y_{cal}, Z_{cal}, P_{cal}, I_{cal})$ are the calculated values using the initial estimates of the rate equation parameters.

The user can also calculate the subtracted IM response from the measured IM response curves (Figure1) and load a file with this information into the component.

This will allow a pre-optimization step, where the component fits the parameters Z and Y to the measured results.

Figure 1 Measured IM responses



The file format for the subtracted IM response data is the following:

Frequency0 SubtractedIM0

Frequency1 SubtractedIM1

Frequency2 SubtractedIM2

...

FrequencyN SubtractedIMN

The units are GHz and dB respectively.

The laser measured can also include the turn-on delay parameter in the optimization process. In this case, the turn-on delay value specified defines the time needed for the carrier density to reach the threshold carrier density when the laser current rises to the reference current. The calculation of the turn-on delay is based on the definition find in [1].The laser linewidth parameter can be included in the optimization process by defining the linewidth value for the laser when the bias current is the reference current parameter [4]. The RIN is calculated according to [2][3] and the user has to define the average RIN value in the defined frequency range.

References

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