



# EPIC Online Technology Meeting on VCSEL Technology and Applications

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# Introduction - I

- Optiwave established in 1994
- Located in Ottawa, Ontario, Canada
- Optiwave develops innovative software tools that offer **design**, simulation, and **optimization capabilities** for components, links, systems and networks
- Optiwave's software **offers** users a **distinct competitive advantage** through
  - vastly **shortening product time introduction** to the market
  - dramatically **improving product quality**
  - **enhancing** productivity and cost-effectiveness

- Optiwave's software has been **licensed to more than 1000 industry-leading corporations, universities, research and governmental institutions** in over than **75 countries** worldwide.
- Customers sample and their field of operation :
  - **Photonic component and module suppliers:** VIAVI Solution & Lumentum (JDS Uniphase), Oclaro, Corning, 3M, LG, Intel and Oki Electric
  - **Optical telecommunication equipment providers:** Nokia (Alcatel/Lucent), Huawei, Mitsubishi, NEC, IPG Photonics and Ciena
  - **Telecommunication Service providers:** NTT, AT&T and Bell Canada
  - **National defense contractors:** Lockheed Martin, Raytheon, Boeing, BaeSystems and Thales
  - **Non-profit organizations:** Sandia National Laboratories, Battelle, National Research Council of Canada, and Communications Research Centre
  - **Universities:** Harvard, MIT, Stanford, Ottawa, Toronto, McGill, Nanyang, Shanghai and Tokyo University

# Product Line

## System-Level



**OptiSystem**

Optical Communication System  
and Amplifier Design Suite



**OptiSPICE**

The First Opto-Electronic Circuit  
Design Software

## Component-Level



**OptiBPM**

Waveguide Optics Design Software



**OptiFDTD**

Finite-Difference Time-Domain  
Simulation Design



**OptiFiber**

Optical Fiber Design Software



**OptiGrating**

Integrated and Fiber Optical Gratings  
Design Software

Instrumentation-Level



**OptiInstrument**

Instruments Communication and Control Tool

- **Allow remote** communication & control of instruments
- Setup parameters of equipment
- **Automate** testing and characterization
- View generated signals
- **Extract & save** the data of generated signals for post processing
- **Integrate** instruments with photonics and systems simulation tools

**Opto-electronic Circuits** (Ring resonators, Laser drivers, Optical interconnects)

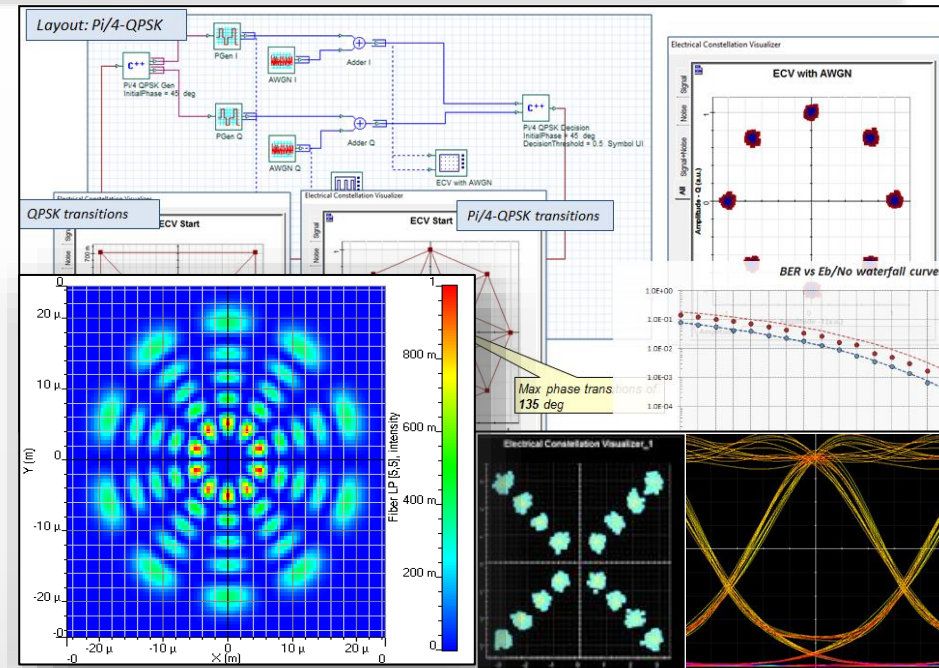
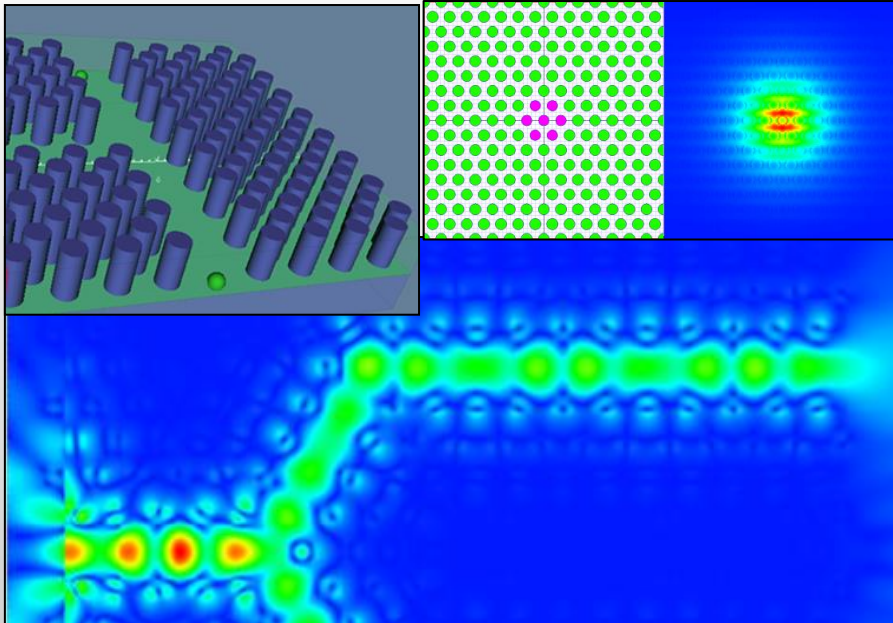
**Optical Networks** (OTDM, SONET/SDH rings, CWDM, DWDM, PON, OCDMA)

**Optical Amplifiers & Lasers** (EDFA, SOA, Raman, Hybrid, GFF optimization, Parametric, Fiber Lasers)

**Modulation formats** (RZ, NRZ, CSRZ, DB, DPSK, QPSK, DP-QPSK, PM-QPSK, QAM)

**Optical Wireless Communication** (LiFi, Satellite, FSO, VLC, 5G backbone)

**Sensors** (FBG sensor, Phi-OTDR, OTDR)



**Finite-Difference Time-Domain** (Dielectric and metallic gratings, photonic crystals, nanoparticles)

**Beam Propagation Method** (couplers, splitters, modulators, multiplexers, AWGs)

**Optical Gratings** (Filters, Fiber Bragg reflectors, Gain flattening elements, dispersion compensators)

**Optical Fiber** (Fiber characterization, visualizing multimode interference patterns, fiber sensors)

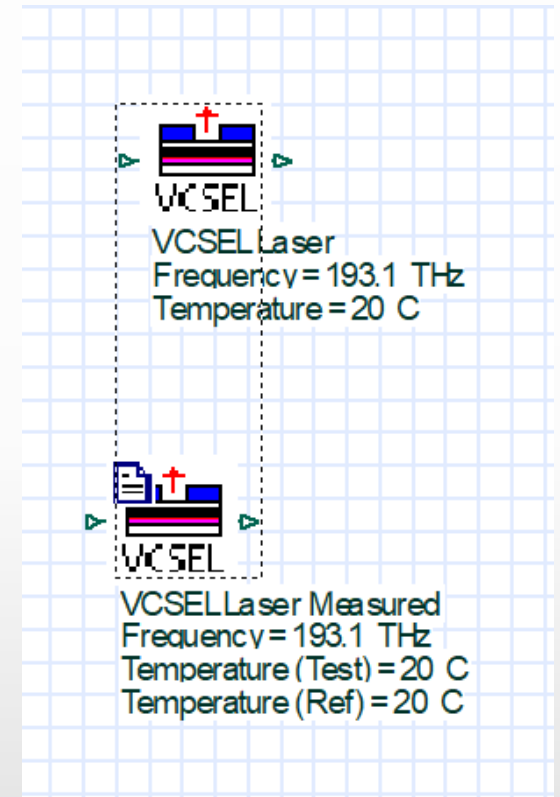
**Mode Solving** (Polarization splitter with holey fiber, polarization independent waveguide)

- **Optical Wireless Communication:** LiFi, Satellite, FSO, VLC, 5G backbone
- Microwave Photonics
  - **Large component library** (lasers, modulators, filters, detectors, amplifiers, signal processing, etc....)
  - **Large library of visualizers** for optical, electrical and binary signals
- **LIDAR system:** laser pulse **time of flight** range measurement, **phase-shift** range measurement, **Frequency Modulation Continuous Wave (FMCW)**
- Sensor Systems: FBG, **Phi-OTDR**, Gyroscopes, **OTDR**
- Digital signal processing: DSP
- **Advanced coherent modulation systems:** mQAM, mPAM, mPSK, etc...



# VCSEL Components

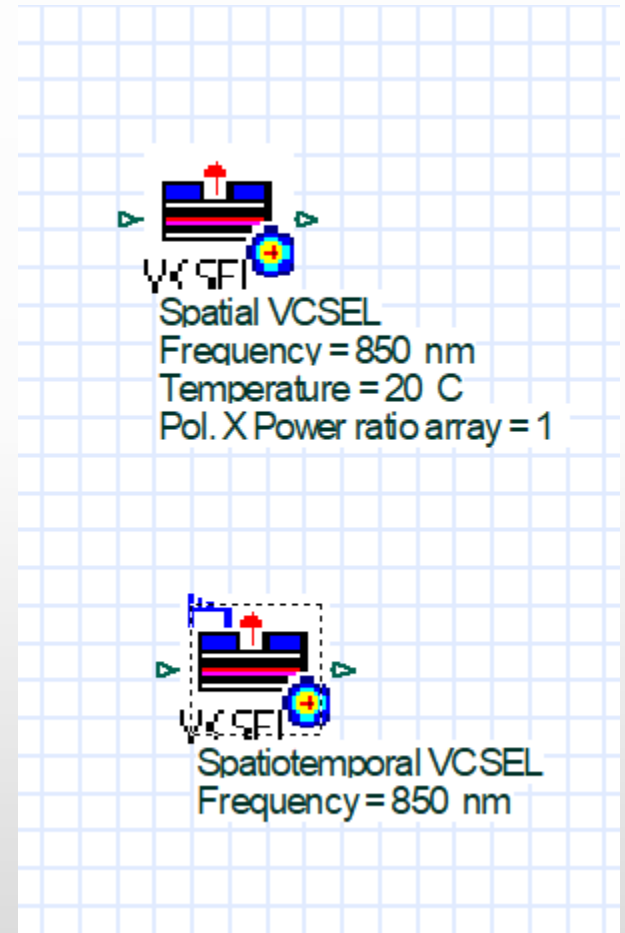
- VCSEL Laser
  - Models include
    - Thermal effects
    - Parameter fitting based on measured LI and IV curves
- VCSEL Laser Measured
  - Models similar to VCSEL Laser
  - Allows users to extract the laser rate parameters from measurements of threshold current, optical power, resonance frequency and damping factor





# VCSEL Components

- Spatial VCSEL
  - Models transverse mode profile
  - Mainly used with MMF
- Spatiotemporal VCSEL
  - Uses 2D spatially-dependent rate equations
  - Accounts dynamically for spatial interaction between optical field and carrier distribution in active layer



# VCSEL Laser

OptiSystem - [Project1]

File Edit View Layout Tools Report Script Add-Ins Window Help

Layout1 Sweep Iteration 1

Component Library

Default/Transmitters Library/Optical Sources/

- CW Laser
- Ideal Single Mode Laser
- Laser Measured
- LED
- White Light Source
- Pump Laser
- Pump Laser Array
- CW Laser Array
- CW Laser Measured
- Directly Modulate...
- CW Laser Array ES
- VCSEL Laser
- Controlled Pump Laser
- Fabry Perot Laser
- VCSEL Laser Measured
- DFB Laser
- Empirical Laser M...
- Spectral Light Source
- Set OSNR

VCSEL Laser Properties

Label: VCSEL Laser

Disp	Thermal	Physical	Measurements	Numerical	Graphs	Simulation	Noise	Random numbers	Custom order
		Name							
<input type="checkbox"/>		Reduce parameters							<input checked="" type="checkbox"/>
<input type="checkbox"/>		Active layer volume						10e-012	cm^3
<input type="checkbox"/>		Group velocity						8.5e+009	cm/s
<input type="checkbox"/>		Quantum efficiency						0.4	
<input type="checkbox"/>		Differential gain coefficient						0.25e-015	cm^2
<input type="checkbox"/>		Carrier density at transparency						1e+018	cm^-3
<input type="checkbox"/>		Mode confinement factor						1	
<input type="checkbox"/>		Scaling factor						26e-009	W
<input type="checkbox"/>		Gain coefficient						0.016e+006	1/s
<input type="checkbox"/>		Carrier number at transparency						19.4e+006	
<input type="checkbox"/>		Carrier lifetime						5e-009	s
<input type="checkbox"/>		Photon lifetime						2.28e-012	s
<input type="checkbox"/>		Spontaneous emission factor						1e-006	
<input type="checkbox"/>		Gain compression coefficient						10e-018	cm^3
<input type="checkbox"/>		Linewidth enhancement factor						5	
<input type="checkbox"/>		Injection efficiency						1	

VCSEL Laser  
Frequency = 193.1 THz  
Temperature = 20 C

Main Layout

Layout Report Script

Project1

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



# VCSEL Laser Measured

OptiSystem - [Project1]

File Edit View Layout Tools Report Script Add-Ins Window Help

Layout 1 Sweep Iteration 1

Bit rate (bits/sec): 1e+010 Sequence length (bits): 1024 Author: Tuesday, May 05, 2020 Sweep iteration: 1/1  
 Samples per bit: 32 Sample rate (Hz): 3.2e+011 Number of samples: 32768 Symbol rate (symbols/sec): 1e+010 Time window (s): 1.024e-007 Guard bits: 0

**VCSEL Laser Measured Properties**

Label: VCSEL Laser Measured

Main Thermal Physical **Measurements** Numerical Graphs Simulation Noise Random numbers Custom order

Disp	Name	Value	Units	Mode
<input type="checkbox"/>	Frequency response data type	Parameters		Normal
<input type="checkbox"/>	Damping factor	10.28	1e9 s^-1	Normal
<input type="checkbox"/>	Resonance frequency data	<input type="checkbox"/>		Normal
<input type="checkbox"/>	Resonance frequency factor	6.43	1e20 Hz^2	Normal
<input type="checkbox"/>	Resonance frequency	3.87	GHz	Normal
<input type="checkbox"/>	Subtracted IM response filename	SubtractedResponse.dat		Normal
<input type="checkbox"/>	Threshold current	18	mA	Normal
<input type="checkbox"/>	Reference current	23	mA	Normal
<input type="checkbox"/>	Slope efficiency data	<input checked="" type="checkbox"/>		Normal
<input type="checkbox"/>	Slope efficiency	0.3	mW/mA	Normal
<input type="checkbox"/>	Power at reference current	1.5	mW	Normal
<input type="checkbox"/>	Linewidth data	<input type="checkbox"/>		Normal
<input type="checkbox"/>	Linewidth	10	MHz	Normal
<input type="checkbox"/>	Average RIN data	<input type="checkbox"/>		Normal
<input type="checkbox"/>	RIN start	0.2	GHz	Normal
<input type="checkbox"/>	RIN stop	15	GHz	Normal
<input type="checkbox"/>	Average RIN	-140	dB/Hz	Normal
<input type="checkbox"/>	Max input current	40	mA	Normal
<input type="checkbox"/>	a - Ioff(T)	1.246e-3 -2.545e-5 2.908e-7 -2.531e-10 1.022e-12		Normal
<input type="checkbox"/>	b - V(T)	1		Normal
<input type="checkbox"/>	c - V(I)	1.721 275 -2.439e4 1.338e6 -4.154e7 6.683e8 -4.296e		Normal
<input type="checkbox"/>	Parameter fitting	<input checked="" type="checkbox"/>		Normal
<input type="checkbox"/>	LI curves filename	LI_Temperature.dat		Normal
<input type="checkbox"/>	IV curves filename	IV_Temperature.dat		Normal
<input type="checkbox"/>	LI curves at different temperatures (A C W)	183 x 3		Normal
<input type="checkbox"/>	IV curves at different temperatures (A C V)	78 x 3		Normal

VCSEL Laser Measured  
 Frequency = 193.1 THz  
 Temperature (Test) = 20 C  
 Temperature (Ref) = 20 C

Project Browser: Default, Layout 1, Global, VCSEL Laser Measured

Main Layout | Layout | Report | Script | Project1

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

OptiSystem - [Project1]

File Edit View Layout Tools Report Script Add-Ins Window Help

Layout 1 Sweep Iteration 1

Layout: Layout 1 Author: Tuesday, May 05, 2020 Sweep iteration: 1/1

Bit rate (bit/s): 1e+010 Sequence length (bits): 1024 Samples per bit: 32 Sample rate (Hz): 3.2e+011 Number of samples: 32768 Symbol rate (symbols/sec): 1e+010 Time window (s): 1.024e-007 Guard bits: 0

Component Library

Default/Multimode Library/Transmitters/

- Spatial Optical Tr...
- Spatial CW Laser
- Spatial single mo...
- Spatial LED
- Spatial VCSEL
- Spatiotem... VCSEL

Spatial VCSEL Properties

Label: Spatial VCSEL

Main Thermal Physical Measurements **Spatial effects** Numerical Graphs Simulation Noise Random numbers Custom order

Disp	Name	Value	Units	Mode
<input type="checkbox"/>	Mode polarization	X = Y		Normal
<input checked="" type="checkbox"/>	Pol. X Power ratio array	1		Normal
<input type="checkbox"/>	Pol. Y Power ratio array	1		Normal
<input type="checkbox"/>	Pol. X Mode type	Laquerre-Gaussian		Normal
<input type="checkbox"/>	Pol. Y Mode type	Laquerre-Gaussian		Normal
<input type="checkbox"/>	Pol. X m,n index array	0 0		Normal
<input type="checkbox"/>	Pol. Y m,n index array	0 0		Normal
<b>Laquerre-Gaussian and Hermite-Gaussian parameters</b>				
<input type="checkbox"/>	Pol. X spot size		5 um	Normal
<input type="checkbox"/>	Pol. X inv. radius of curvature		0 1/um	Normal
<input type="checkbox"/>	Pol. Y spot size		5 um	Normal
<input type="checkbox"/>	Pol. Y inv. radius of curvature		0 1/um	Normal
<b>Fiber LP parameters</b>				
<input type="checkbox"/>	Refractive index profile	Parabolic index		Normal
<input type="checkbox"/>	Core radius	25 um		Normal
<input type="checkbox"/>	Cladding thickness	10 um		Normal
<input type="checkbox"/>	Core or peak refractive index	1.45		Normal
<input type="checkbox"/>	Refractive index step (contrast)	1.369797859690831	%	Normal
<input type="checkbox"/>	Numerical aperture	0.24		Normal
<input type="checkbox"/>	Refractive index cladding	1.43		Normal
<input type="checkbox"/>	Alpha	2		Normal
<input type="checkbox"/>	Number of radial steps	1000		Normal
<input type="checkbox"/>	Optifiber file format			Normal
<input type="checkbox"/>	Refractive index file name	Index.dat		Normal

Project Browser

Default

Name	Value
Layout 1	1
Global	
Spatial VCSEL	Spatial ...

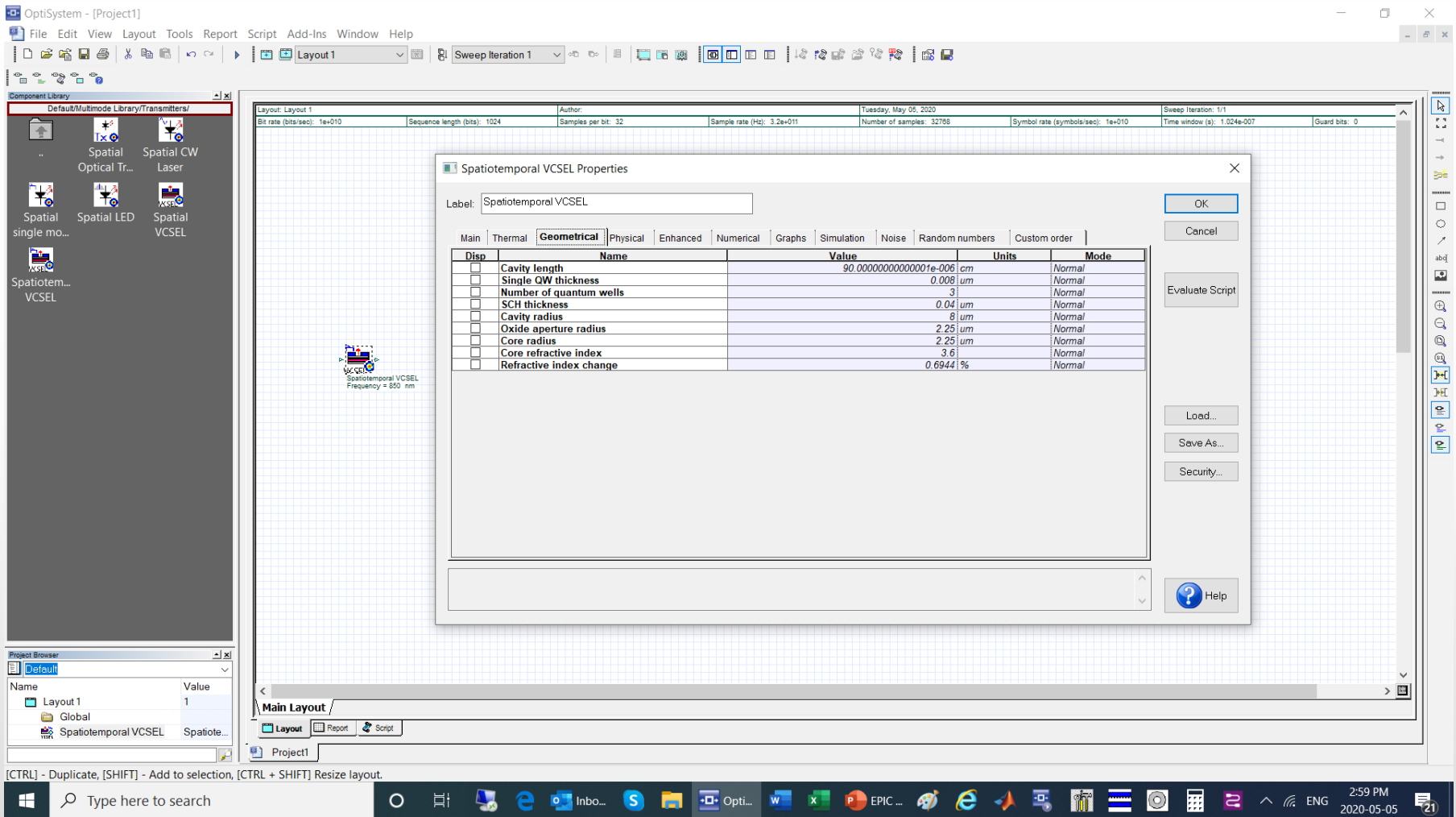
Main Layout /

Layout Report Script

Project1

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

# Spatiotemporal VCSEL



OptiSystem - [Project1]

File Edit View Layout Tools Report Script Add-Ins Window Help

Layout 1 Sweep Iteration 1

Component Library: Default/Multimode Library/Transmitters/

Layout: Layout 1 Author: Tuesday, May 05, 2020 Sweep Iteration: 1/1

Bit rate (bits/sec): 1e+010 Sequence length (bits): 1024 Samples per bit: 32 Sample rate (Hz): 3.2e+011 Number of samples: 32768 Symbol rate (symbols/sec): 1e+010 Time window (s): 1.024e-007 Guard bits: 0

Spatiotemporal VCSEL Properties

Label: Spatiotemporal VCSEL

Main Thermal **Geometrical** Physical Enhanced Numerical Graphs Simulation Noise Random numbers Custom order

Disp	Name	Value	Units	Mode
<input type="checkbox"/>	Cavity length	90.000000000000001e-006	cm	Normal
<input type="checkbox"/>	Single QW thickness	0.008	um	Normal
<input type="checkbox"/>	Number of quantum wells	3		Normal
<input type="checkbox"/>	SCH thickness	0.04	um	Normal
<input type="checkbox"/>	Cavity radius	8	um	Normal
<input type="checkbox"/>	Oxide aperture radius	2.25	um	Normal
<input type="checkbox"/>	Core radius	2.25	um	Normal
<input type="checkbox"/>	Core refractive index	3.6		Normal
<input type="checkbox"/>	Refractive index change	0.6944	%	Normal

Project Browser: Default

Name Value

Layout 1 1

Global

Spatiotemporal VCSEL Spatiote...

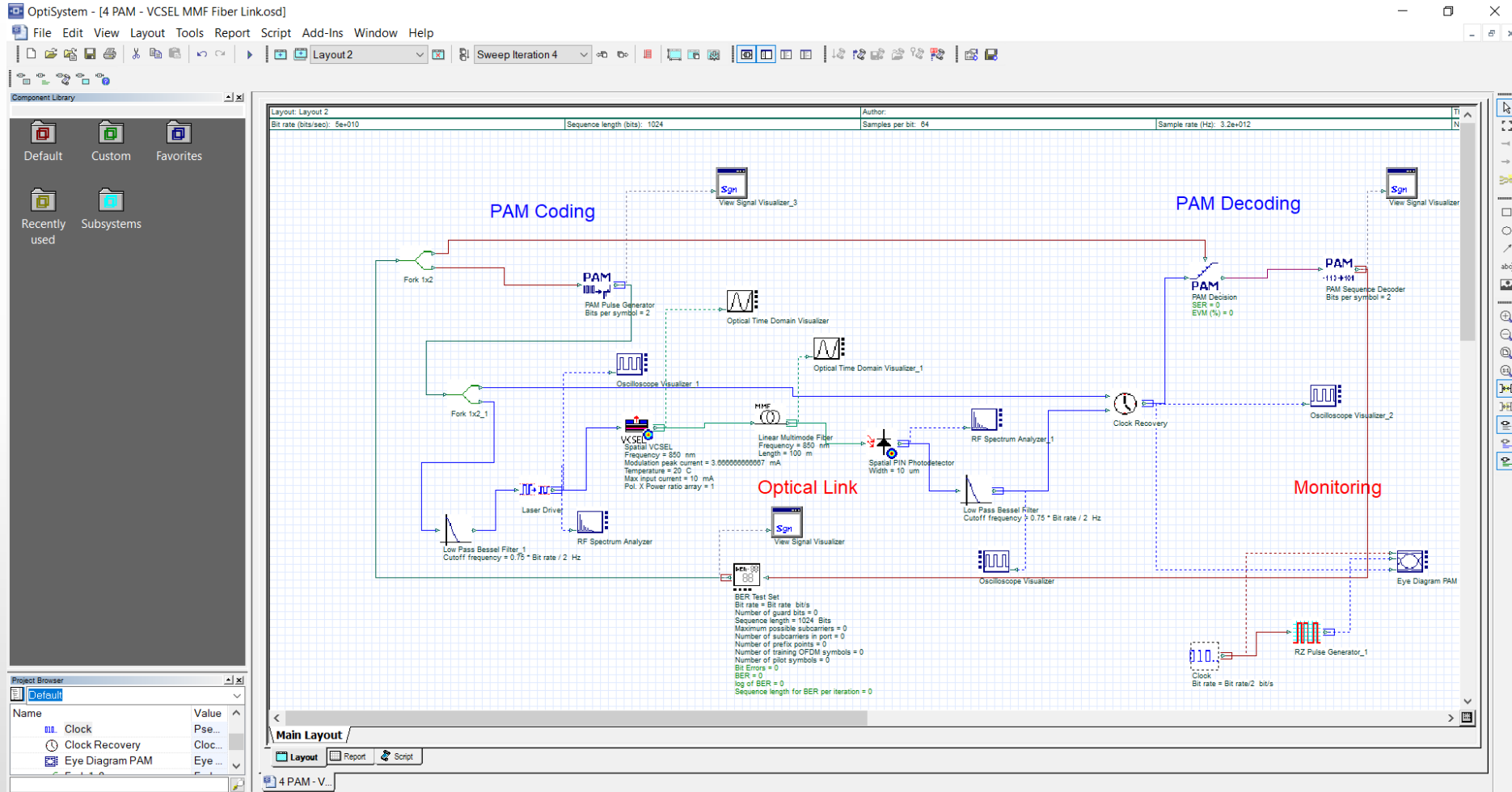
Project1

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

Windows taskbar: Type here to search, Opti..., EPIC..., 2:59 PM 2020-05-05

Accounts dynamically for spatial interaction between optical field and carrier distribution in active layer

# 4 PAM - VCSEL MMF Fiber Link



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

OptiSystem - [VCSEL Laser Measured Impulse response.osd]

File Edit View Layout Tools Report Script Add-Ins Window Help

VCSEL Impulse Res Sweep Iteration 1

Component Library

Default Custom Favorites

Recently used Subsystems used

Layout: VCSEL Impulse Response

Bit rate (bits/sec): 2.4e+008 Sequence length (bits): 16 Author: Samples per bit: 64 Sample rate (Hz): 1.536e+010

0101 User Defined Bit Sequence Generator Bit rate = Bit rate bits/s

Impulse Generator

VCSEL Laser Measured Frequency = 850 nm Bias current = 10 mA Modulation peak current = 40 mA Temperature (Ref) = 20 C

PIN Photodiode

Optical Power Meter Total Power (dBm) = 0 Signal Power (dBm) = 0

RF Spectrum Analyzer

Oscilloscope Visualizer

Optical Spectrum Analyzer

Optical Time Domain Visualizer

RF Spectrum Analyzer\_1

0101 User Defined Bit Sequence Generator\_1 Bit rate = Bit rate bits/s

Impulse Generator\_1

VCSEL Laser Measured Frequency = 850 nm Bias current = 10 mA Modulation peak current = 40 mA Temperature = 25 C

PIN Photodiode\_1

Optical Power Meter\_1 Total Power (dBm) = 0 Signal Power (dBm) = 0

RF Spectrum Analyzer\_1

RF Spectrum Analyzer\_2

There is a single impulse applied to the VCSEL. Control the Time window to have one impulse. The threshold current is swept there is no noise in the pin detector

Project Browser

Name	Value
PIN Photodiode	PIN...
PIN Photodiode_1	PIN...
RF Spectrum Analyzer	RF S...
RF Spectrum Analyzer_1	RF S...
RF Spectrum Analyzer_2	RF S...

Main Layout

Layout Report Script

VCSEL La...



# Optiwave Spatiotemporal VCSEL Direct Modulation

DESIGN SOFTWARE

The screenshot displays the Optiwave Spatiotemporal VCSEL Direct Modulation software interface. The main workspace shows a circuit diagram for the generation of a direct-modulated spatial optical signal. The components include a Pseudo-Random Bit Sequence Generator (Bit rate = Bit rate, bit/s), an NRZ Pulse Generator, a Spatiotemporal VCSEL (Frequency = 650 nm), and several visualization tools: Spatial Visualizer, Optical Time Domain Visualizer, Optical Spectrum Analyzer, and Oscilloscope Visualizer.

Below the circuit diagram, the following text is displayed:

Generation of direct-modulated Spatial optical signal using a Spatial VCSEL component.  
Thermal effects are also considered.  
15 LP modes

The Spatial Visualizer window is open, showing a 3D Graph of intensity. The Y-axis is labeled Y (m) and ranges from -25 μm to 25 μm. The X-axis is labeled X (m) and ranges from -20 μm to 20 μm. The Z-axis is labeled VCSEL LP [2,2], intensity and ranges from 0 to 1. The plot shows a central spot of high intensity (red/yellow) surrounded by a grid of lower intensity (blue). The plot is titled "3DGraph" and "Mode \ Sum /".

The Spatial Visualizer control panel includes the following settings:

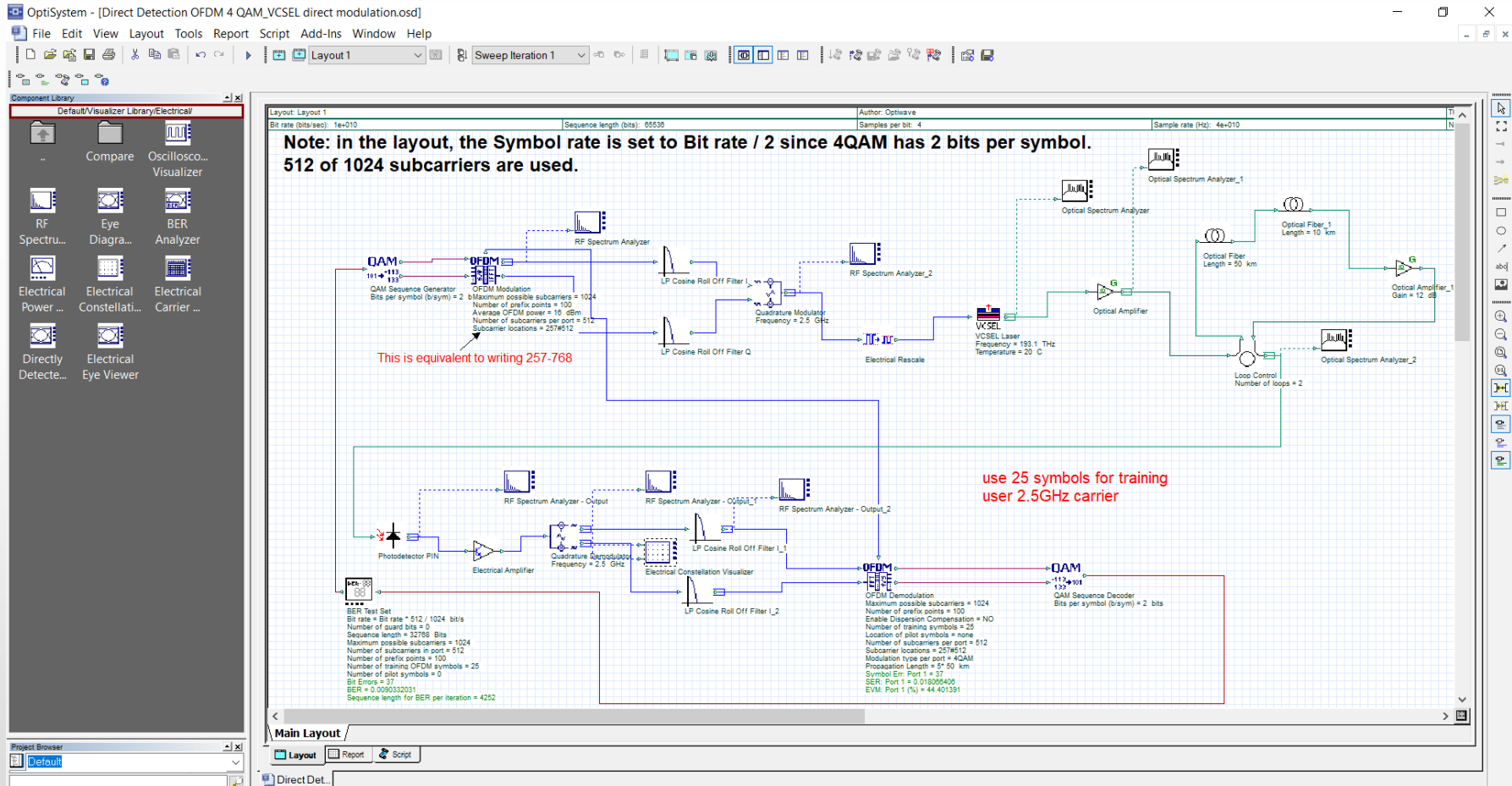
- Signal Index: 0
- Auto Set: [Button]
- Polarization: X
- Format: Polar
- Graph: Power
- Mode number: 14
- Calculate Sum: [Checkbox]

The software interface also shows a Component Library on the left, a Project Browser at the bottom left, and a Main Layout tab at the bottom center.

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

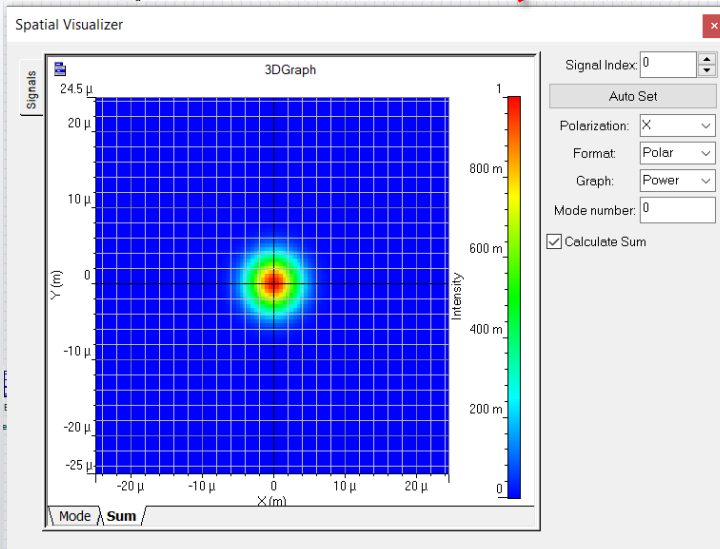
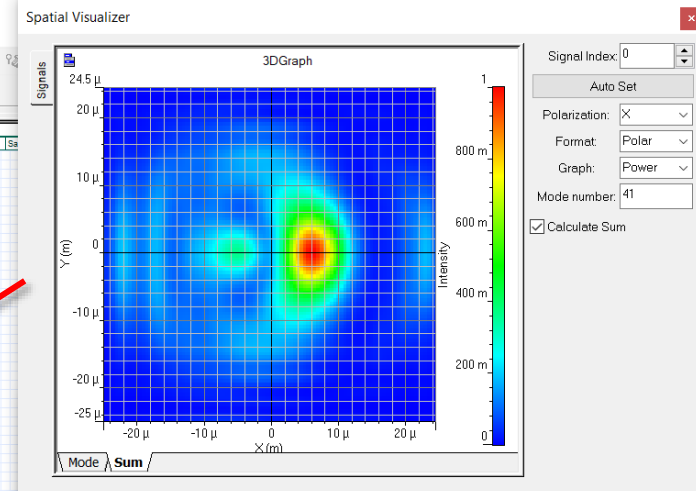
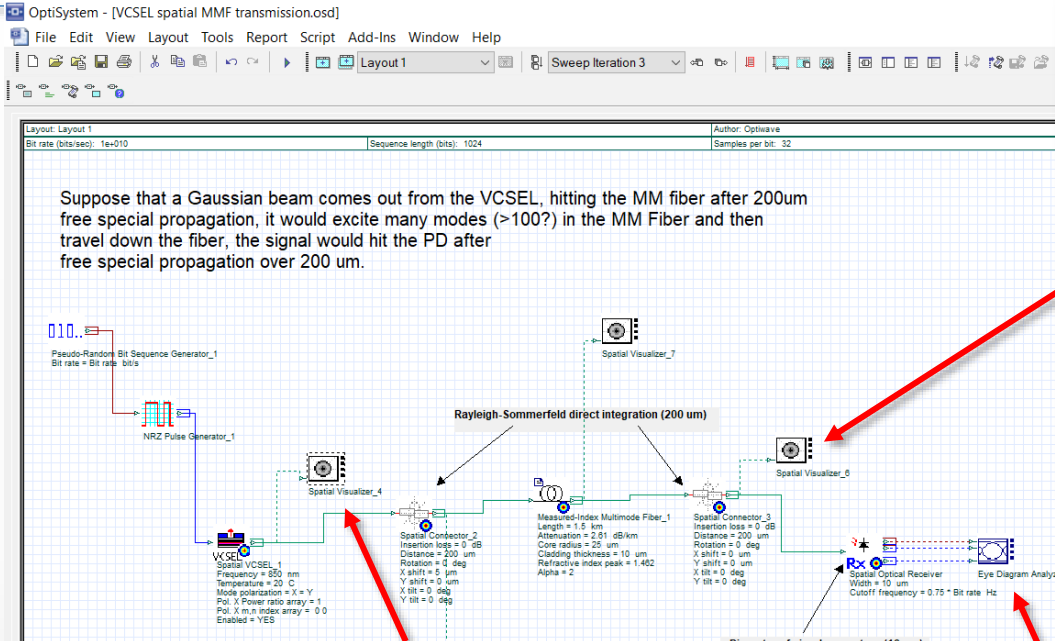


# Direct Detection OFDM 4 QAM using VCSEL direct modulation

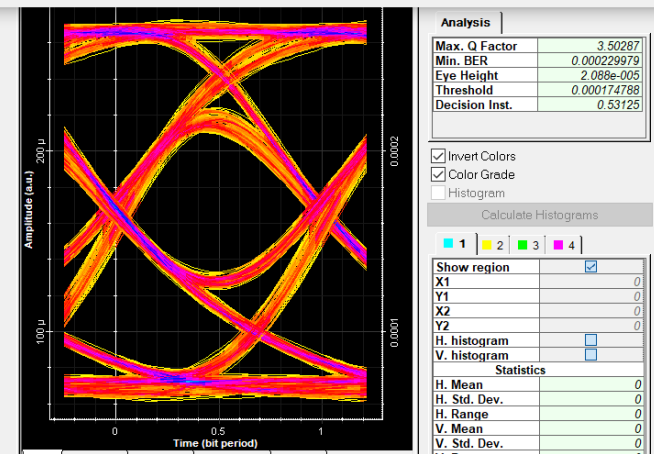


[CTRL] - Duplicate, [SHIFT] - Add to selection, [CTRL + SHIFT] Resize layout.

# Radio over Fiber Simulation



from 0.5 to 5 km





**Thank You**

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- User friendly **GUI**
- Execute **single or sequence** of SCPI commands
- **Load** XML files and all other file formats into GUI panels
- Drag and drop commands with **flexible sequence ordering**
- Generate **Python script** for sequence of commands
- Built in **signal viewer** and **csv file** analysis page
- Built in full **Python script editor**
- **Remote** operation and control of instruments

- Supports **PIC design flow** with Tanner EDA
- Allows PIC simulation from mask level  
(L-Edit >>> S-Edit >>> T-Spice & OptiSPICE)
- **Rapid prototyping**  
(S-Edit >>> T-Spice & OptiSPICE)
- **OptiSPICE models libraries** (.dll + symbols) added to T-Spice
- **Simultaneous simulation** of optics and electronics in same platform