Modeling Free Space Optical Systems

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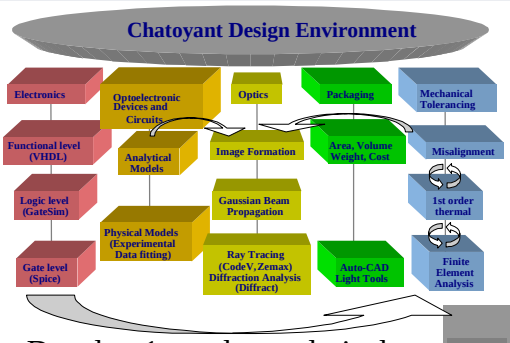
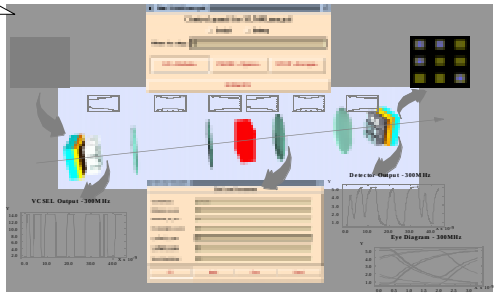
Chatoyant - Goals & Methods



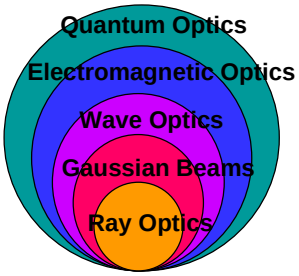
System level O/E CAD tool to:
- Predict performance
- Analyze technology vs. architecture trade-offs
- Without costly prototyping

- Develop 1st order analytical, empirical, and lumped-parameter models for optoelectronic components
- Develop a hierarchical & modular software environment using Ptolemy engine



Models of Optical/Electronic Signals

- Messages are arrays of O/E signals
- Piece-wise linear Intensity or Voltage
- Gaussian shape, angle, position, wavelength, polarization
- Source impedance
- Variable time step (Δt)
  - discrete, continuous, PWL



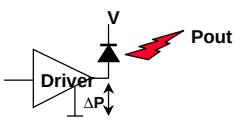
Lumped parameter models

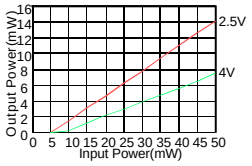
B.E.A. Saleh and M. Teich, *Fundamentals of Photonics*, Wiley, 1991

Models of Components

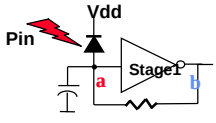
- Analytic models
  - Physics based
- Empirical models
  - Experimental data fitting
- Derived models
  - Parametric models extracted from or verified by lower level tools

$$I(r,z) = I_0\left[\frac{W_0}{W(z)}\right]^2 \exp\left[-\frac{2r^2}{W^2(z)}\right]$$





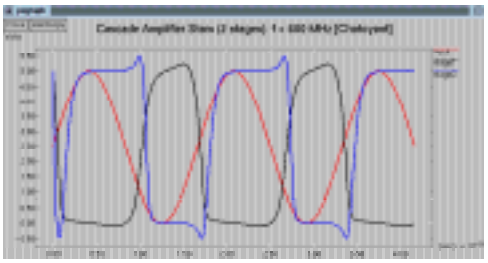
$$P_{out} = \frac{\eta_{LI}/V_{th}}{(1-\eta_{LI}/V_{th})}(P_{in} - I_{th}V_{th})$$



$$V_0(s) = \frac{R_f}{1+\left(\frac{R_f C}{A}\right)s} \cdot P_{optic}(s)$$

Piecewise Linear Model for Time

- **Motivation:**
  - **Modeling dynamic response is necessary.**
- **Problem:**
  - **Small signal model analysis is invalid**
- **Solution:**
  - **Use a mixture of analytic and lumped-parameter models**
  - **CMOS Large Signal Models**
- **Advantages:**
  - **Dynamic time resolution achieves high accuracy at low computation cost**
  - **Homogeneous simulation environment**

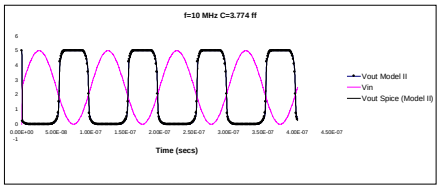


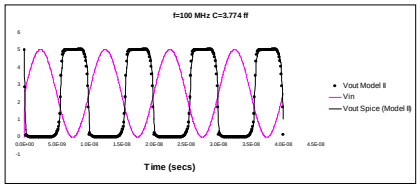
Input **Stage 1 Output** **Stage 2 Output**

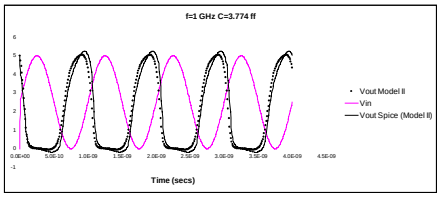
High frequency response in Chatoyant for a cascade driver configuration (f = 600 MHz & C_{ld} = 1fF).

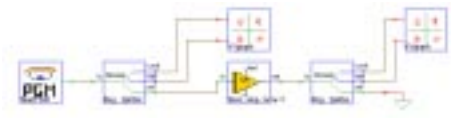
Electrical Drivers (Tests)

	f= 10 MHz C=3.774ff			f= 100 MHz C=3.774ff			f= 1 GHz C=3.774ff		
	Spice Level 2	Model I	Model II	Spice Level 2	Model I	Model II	Spice Level 2	Model I	Model II
Speed									
Time	0.13	0.093	0.15	0.12	0.089	0.091	0.12	0.094	0.089
Iterations	307	100	200	313	100	100	300	100	100
Accuracy	0	9.1%/18.8 SD	1.8%/4.7 SD	0	3.4%/6.8 SD	3.3%/6.7 SD	0	10%/12.9SD	9.99%/13.8SD



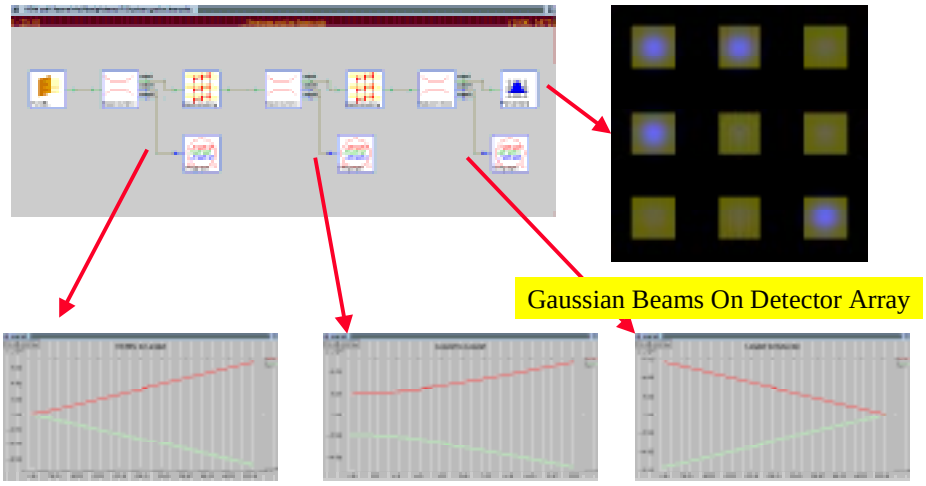






The times for the models include the computational load of the whole system (Chatoyant Implementation).

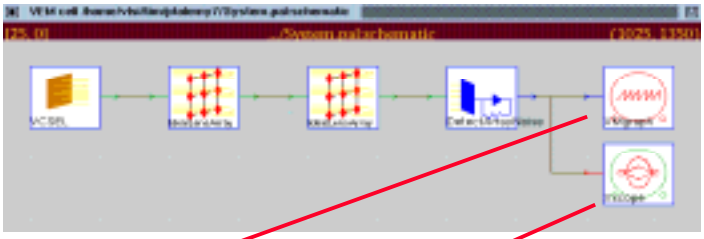
Static Simulation of Gaussian Beam Propagation

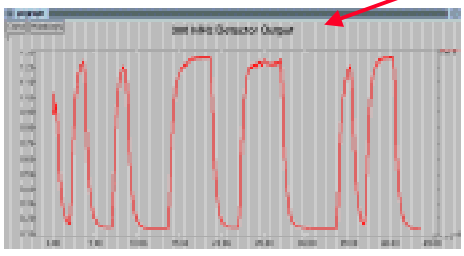


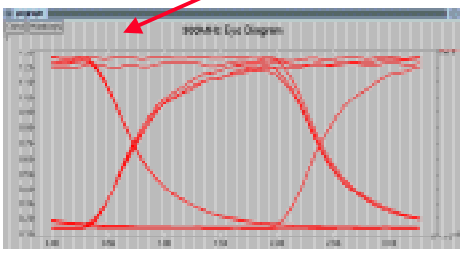
Gaussian Beams On Detector Array

Gaussian Beam propagation

Dynamic Simulation: Detector Response



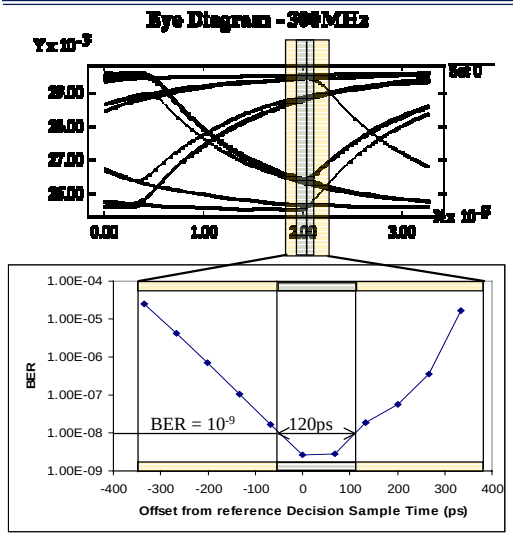


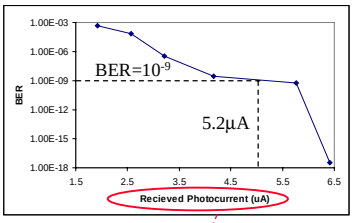


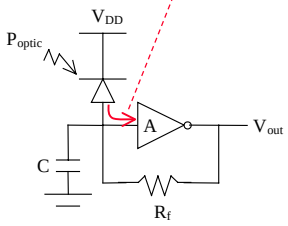
Detector Output

Eye Diagram

BER Modeling

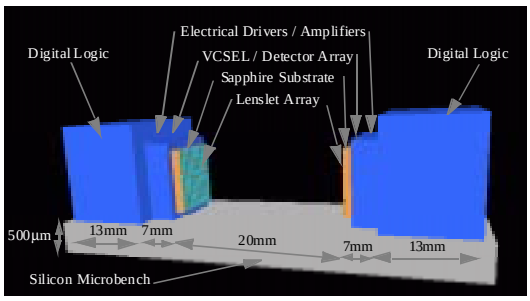


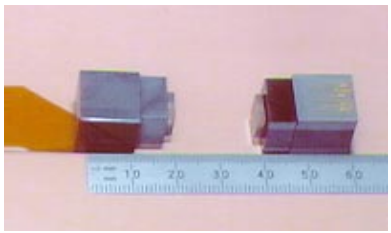




Krishnamoorthy, A.V., Woodward, T.K., Goossen, et. al "Operation of a Single-Ended 550Mbit/s, 41fJ, Hybrid CMOS/MQW Receiver-transmitter", Electronic Letters, April 1996.

System 1: 3D OESP / FFT Demo Prototype



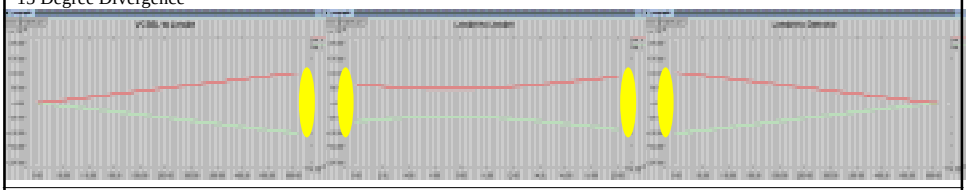


µBench Assembly

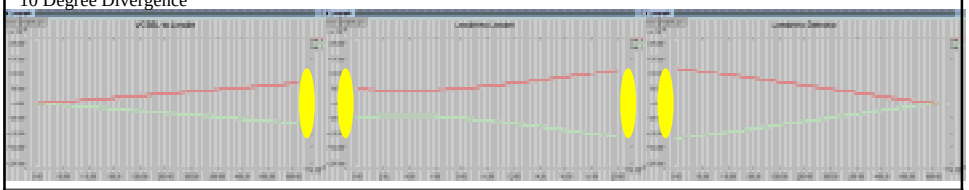
Function: FFT
512x512
32 bits complex
Throughput < 1 msec
Power < 340 W
Volume < 35 cm^3

System Analysis with Different VCSEL Beam Divergence

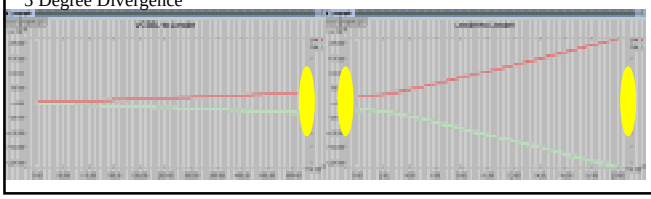
15 Degree Divergence



10 Degree Divergence

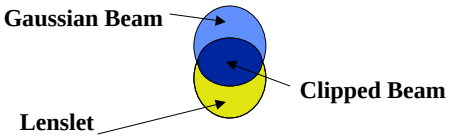


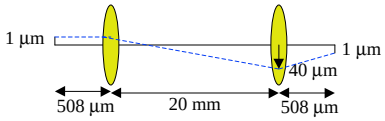
5 Degree Divergence

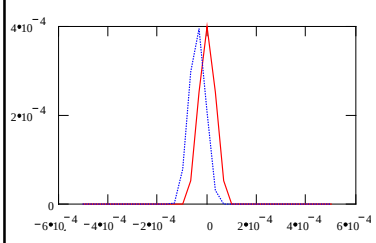


CAN NOT MODEL
NEED SCALAR MODELS…

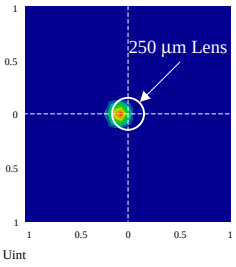
VCSEL 1 μm Mechanical Tolerancing - Scalar Analysis



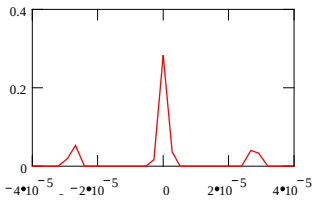




- **At Second Lenslet Plane**
- **Blue is off-axis clipped beam**
- **Red is on-axis clipping**
- **Approximately 40 μm offset**

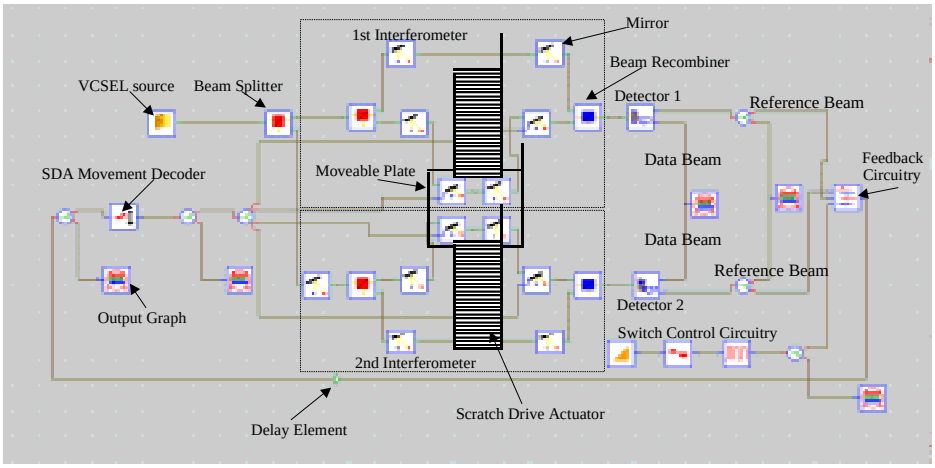


Intensity Distribution Contour At 2nd Lenslet Plane

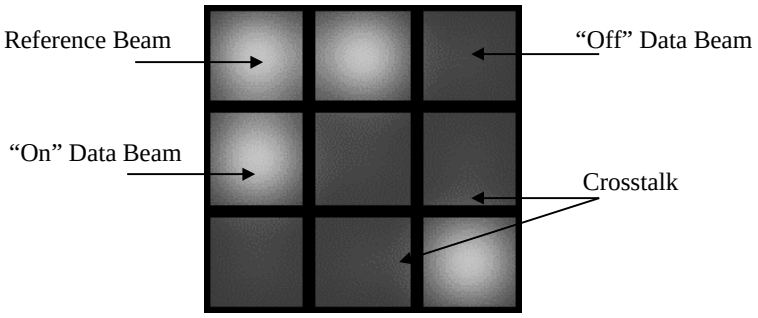


Final Intensity Distribution on the 80mm detector

System2: 1x2 Optical MEM Switch in *Chatoyant*

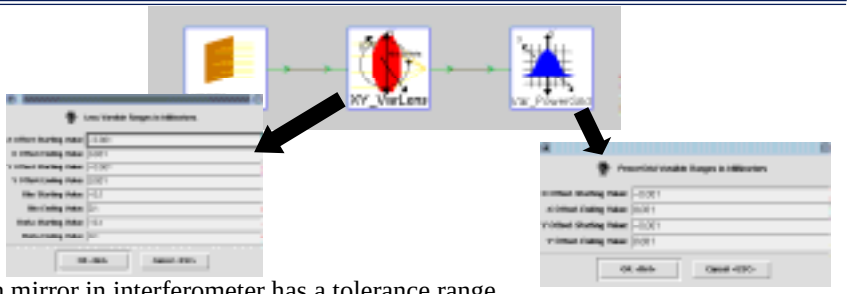


Static Result



- 56% System Efficiency
- -15.5 dB Crosstalk between neighbors
- With 1.0 Degree Offset, Efficiency Drops to 53.5%, Crosstalk Climbs to -11.42

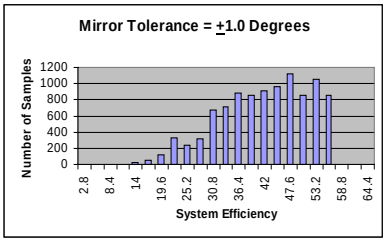
Monte Carlo Mechanical Tolerancing

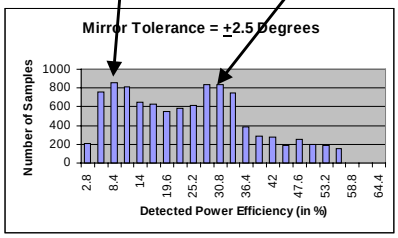


- Each mirror in interferometer has a tolerance range
- No mis-alignment produces a efficiency of 56%

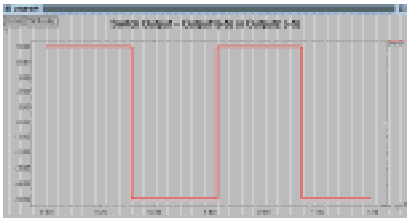
Crosstalk

One Beam Detected

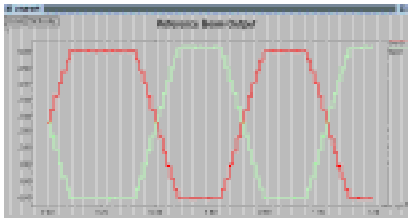




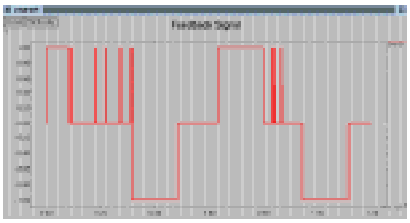
1x2 Switch Dynamic Outputs



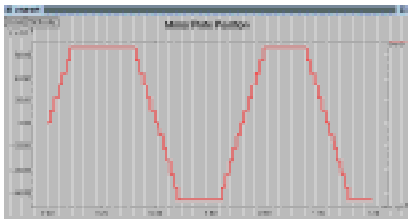
Switch Selection



Reference Beam



Feedback to SDA



Mirror Position

1x2 Switch Output

Chatoyant Development

- **New O/E Message Class**
- **Used New domain (DDF) for multi-rate systems**
- **Multi-platform (SunOS/Linux) support**
- **Use of TCL/TK Scripts for Monte Carlo Analysis**
- **VRML 3D Models**
- **Interfaces to/from low level electronic, optical, thermal & mechanical tools**
- **Non-sequential surfaces, multiple time bases, & multiple energy domains**
- **Ptolemy II???**