Modeling and Simulating Optical MEMS Using Chatoyant

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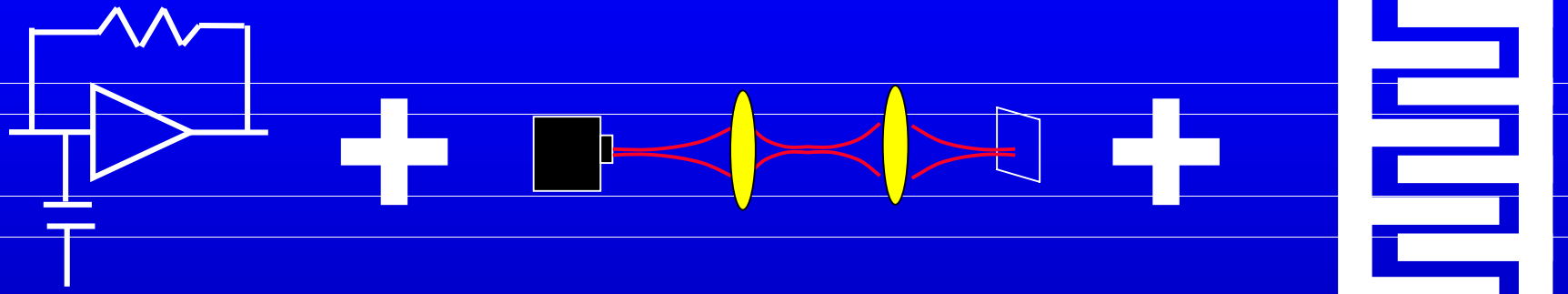
NSF: ECS 96-16879

Overview

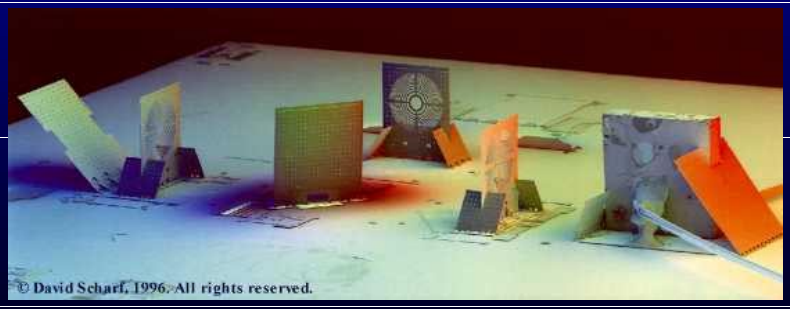
- Introduction and Motivation
- Chatoyant
- Extensions for Optical MEM Modeling
- 3 Example Systems
- Conclusions

What are Optical MEMS….

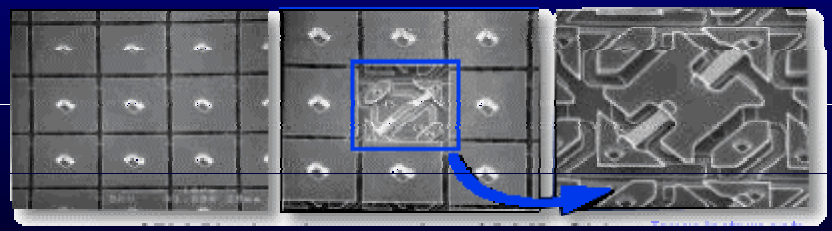


- Electrical Systems
- Optical Systems
- Micro-mechanical

Optical MEMS, MOEMS, OMEMS



Dr. Ming Wu - UCLA - Integrated Free-Space Optical Disk Pickup Head http://www.ee.ucla.edu/labs/laser/

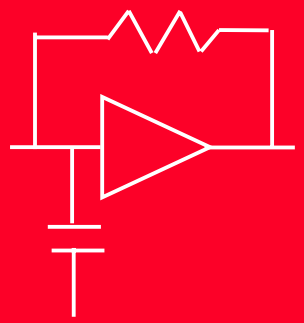


Texas Instruments - DMD - From Darpa http://www.darpa.mil/ETO/MOEMS/DMD/index.html

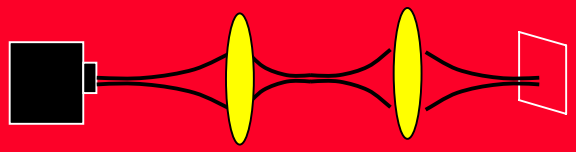
… and why are we modeling them

- Applications for Optical MEMS
  - Scanning, Projection, Display, Switching, Printing, Sensing, Alignment, Modulating, Data Storage
  - MEMS projected $14 Billion Dollars in Sales in 2000 [SPC Study 1994]
- Need for CAD Tools
  - Reduce Costly Prototyping
  - Simulate Systems for Functionality while Analyzing Architecture vs. Technology Trade-offs
- Other Work:
  - MEM System CAD Tools - Microcosm, Tanner, IntelliSense
  - University MEM CAD Research - CMU, MIT….
  - Optical CAD Systems - ORA, Breault Research….

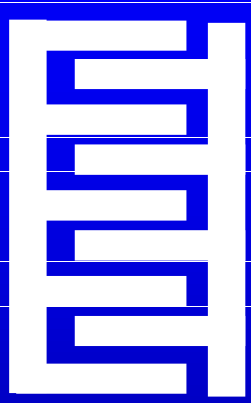
Previous Work: Chatoyant [DAC97]



- Electrical Systems



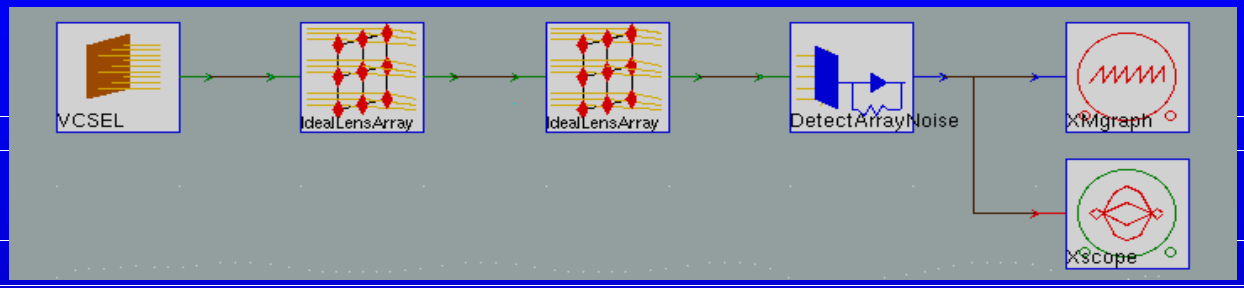
- Optical Systems



- Micro-mechanical

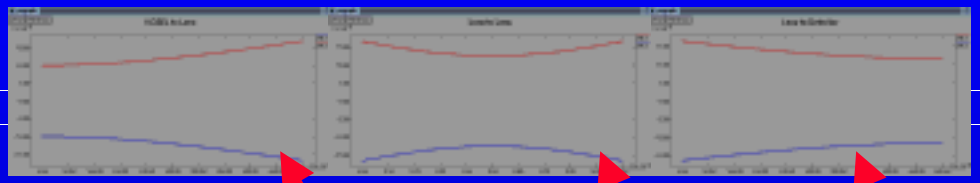
- Created ***Chatoyant***, a Free-Space Opto-Electronic Simulation Framework

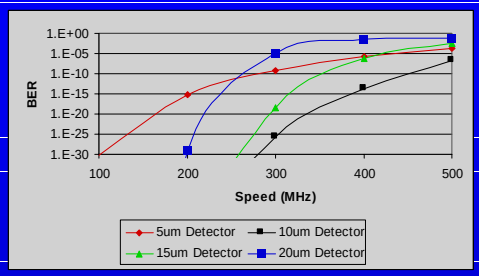
Chatoyant

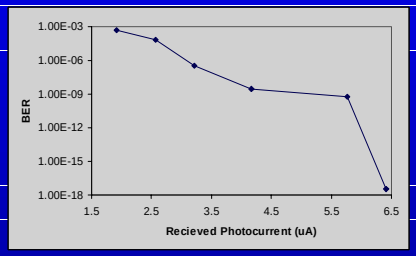


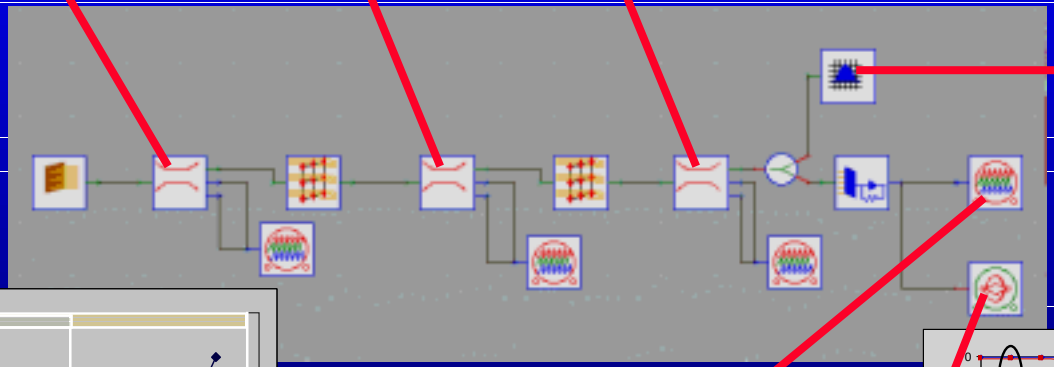
- Multi-domain Simulation Tool
- Built on Classic Ptolemy (UC Berkeley)
  - Icons, called “stars”, are the component models
    - Analytical, empirical, and “lumped parameter” models
  - Lines, or “wires”, are the signal paths
    - Passes “Message” class
    - Supports:
      - Electrical Signals
      - Optical Signals
      - Concept of Time

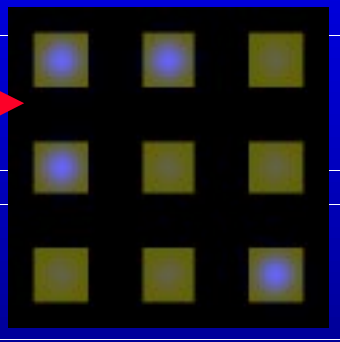
Chatoyant

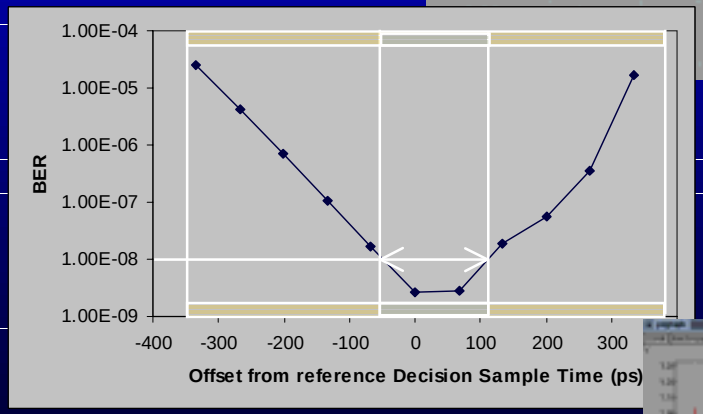


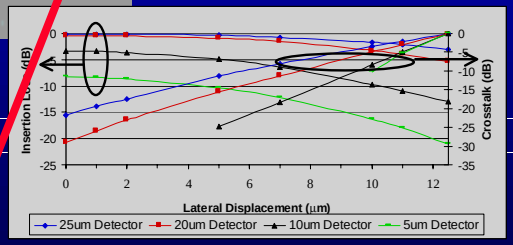

BER
1.E+00
1.E-05
1.E-10
1.E-15
1.E-20
1.E-25
1.E-30
100
200
300
400
500
Speed (MHz)
5um Detector
10um Detector
15um Detector
20um Detector

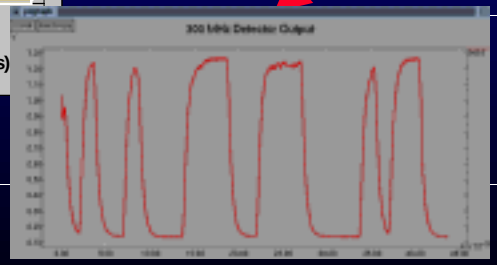

BER
1.00E-03
1.00E-06
1.00E-09
1.00E-12
1.00E-15
1.00E-18
1.5
2.5
3.5
4.5
5.5
6.5
Recieved Photocurrent (uA)

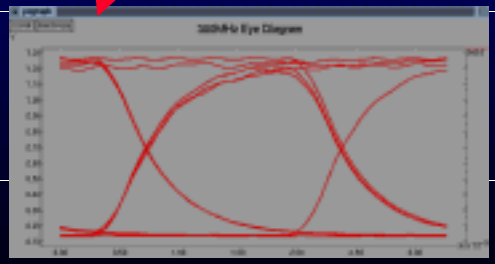





BER
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
-400
-300
-200
-100
0
100
200
300
Offset from reference Decision Sample Time (ps)


Insertion Loss (dB)
Crosstalk (dB)
0
-5
-10
-15
-20
-25
-30
-35
0
2
4
6
8
10
12
Lateral Displacement (μm)
25um Detector
20um Detector
10um Detector
5um Detector

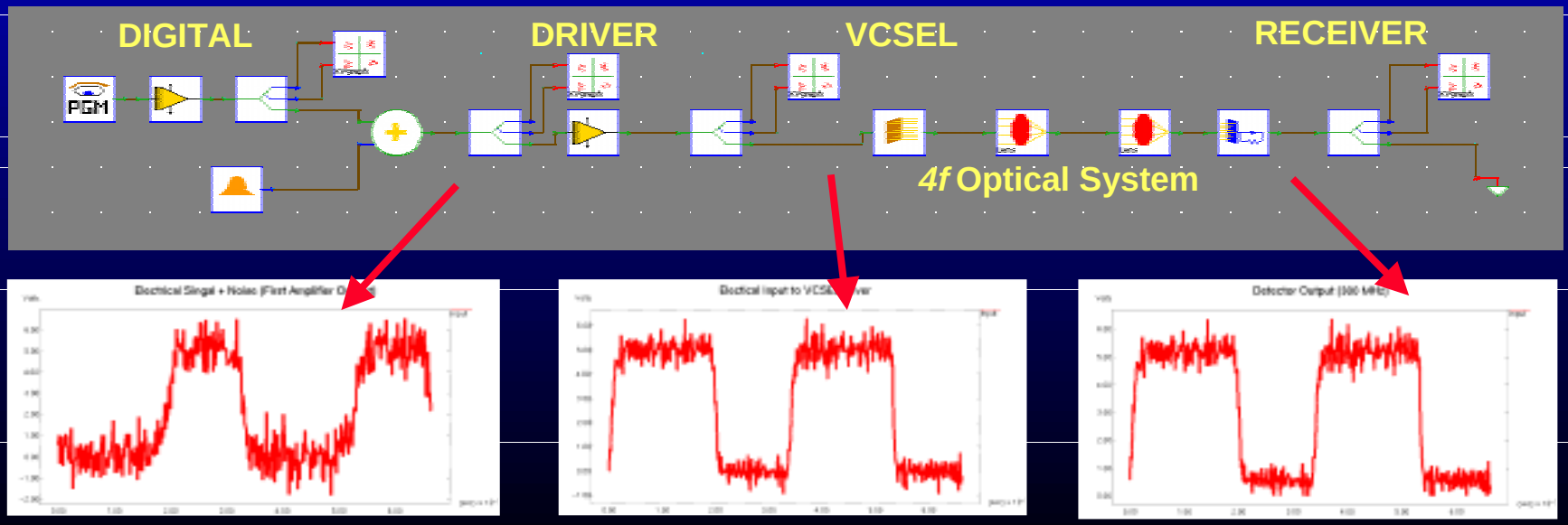




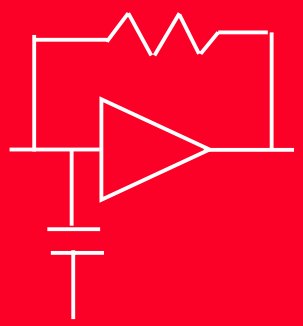
Piece-wise Linear Modeling

Used for optoelectronic devices: electrical drivers, optical receivers, OE modulators

- Based on Modified Nodal Matrix representation
- Linear and non-linear sub-block decomposition
- Piecewise modeling of active devices for the non-linear sub-block
- Re-compute the solution in response to changes between regions of operation

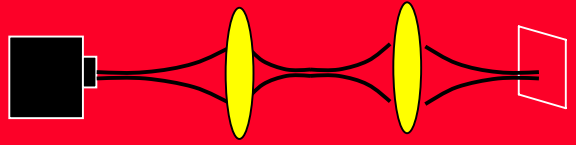


Extensions for Optical MEMS



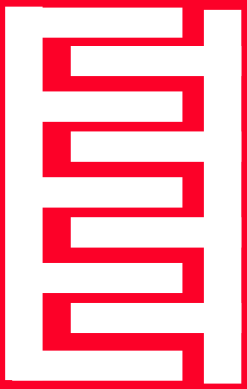
- Electrical Systems

+



- Optical Systems

+



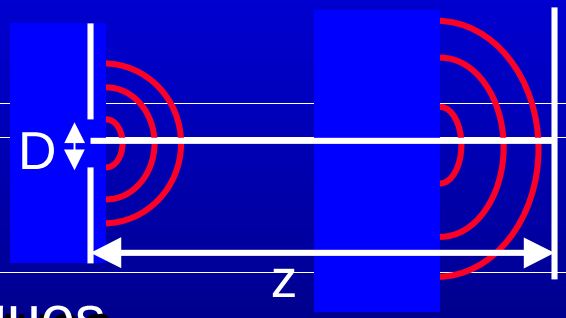
- Micro-mechanical

- Do this by:
  - Models for Diffractive Optics
  - New Models for Components
    - Micro-optical: Micro-Mirrors, Micro-Lenses, Phase Masks
    - Mechanical: Scratch Drive Actuators, Scanning Mirror
  - New Analysis Method
    - Monte Carlo Tolerancing Package

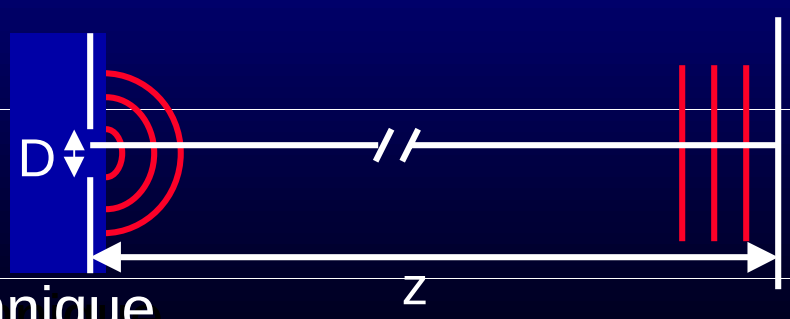
Diffractive Propagation Model

$$U2(x,y) = \frac{e^{jk\left(z+\frac{x^2+y^2}{2z}\right)}}{j\lambda z} \iint U1(\xi,\eta) e^{\frac{jk}{2z}(\xi^2+\eta^2)} e^{\frac{-jk}{z}(x\xi+y\eta)} \partial\xi\partial\eta$$

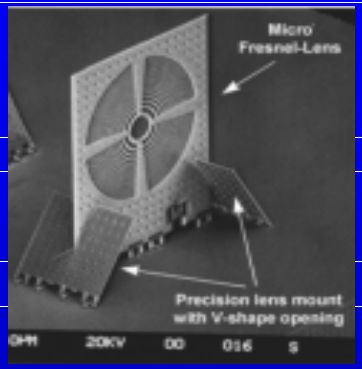
- Fresnel Approximation
  - Near Field - $z < 2D^2/\lambda$
    - Spherical Waves
  - Solve with Explicit Integration Techniques



- Fraunhofer Approximation
  - Far Field - $z > 2D^2/\lambda$
    - Plane Wave Approximation
  - Solve with a FFT Based Technique

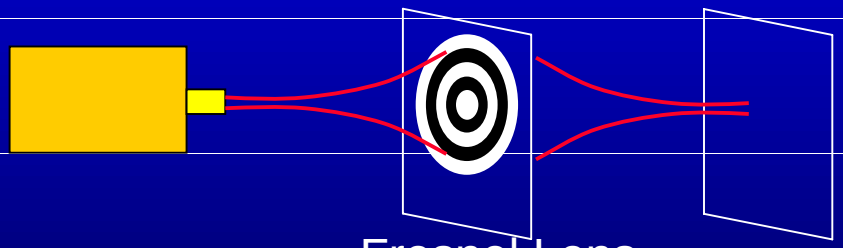


Fresnel Micro-Lens

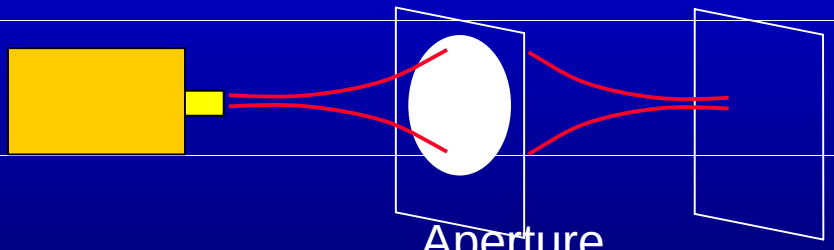


$$p_{fl}(x,y) = \begin{cases} 1, \cos(\pi \dfrac{x^2 + y^2}{\lambda f}) > 0 \\ 0, otherwise \end{cases}$$

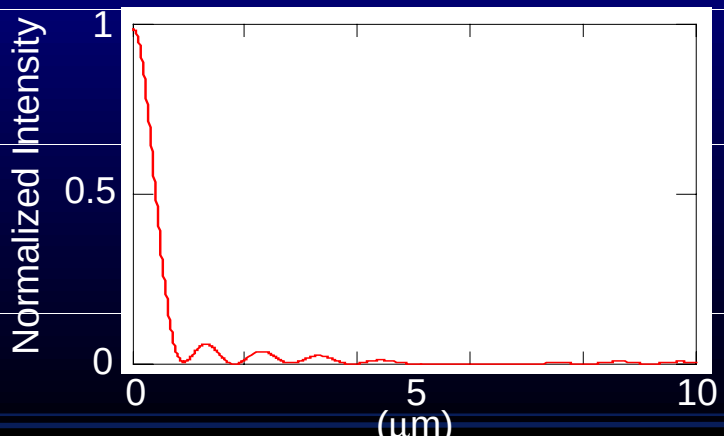
UCLA - Fresnel Lens http://www.ee.ucla.edu/labs/laser/

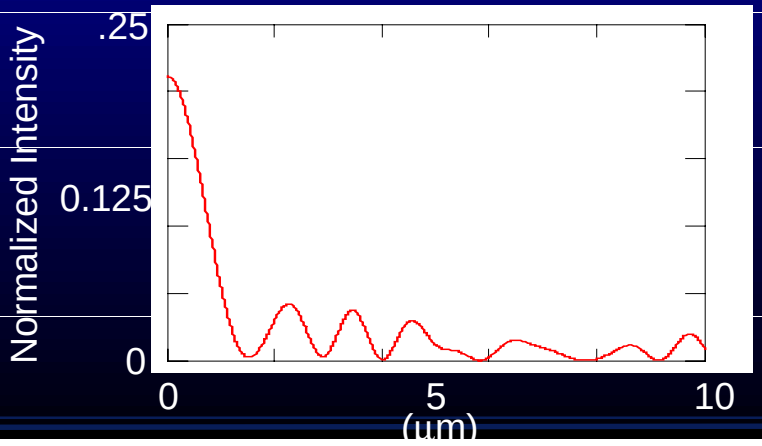


Fresnel Lens



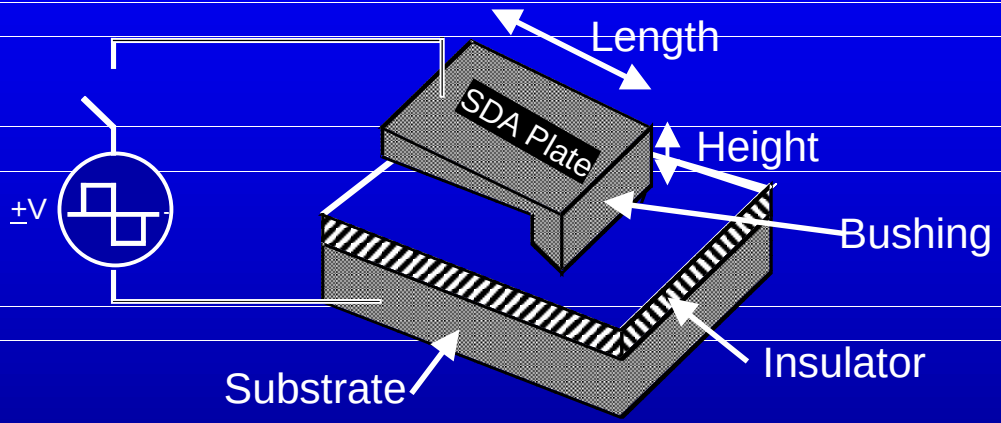
Aperture

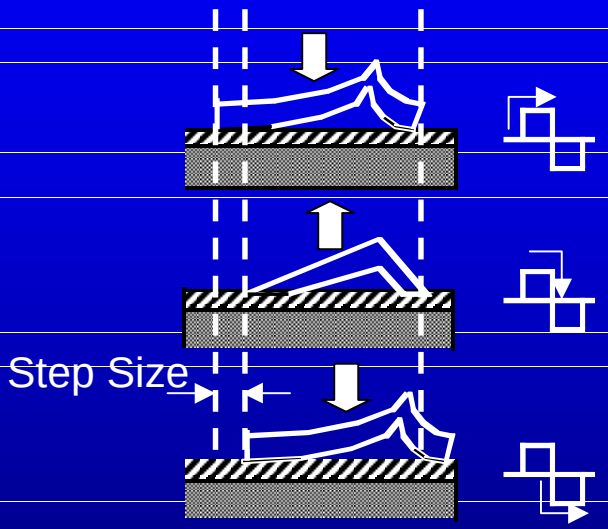




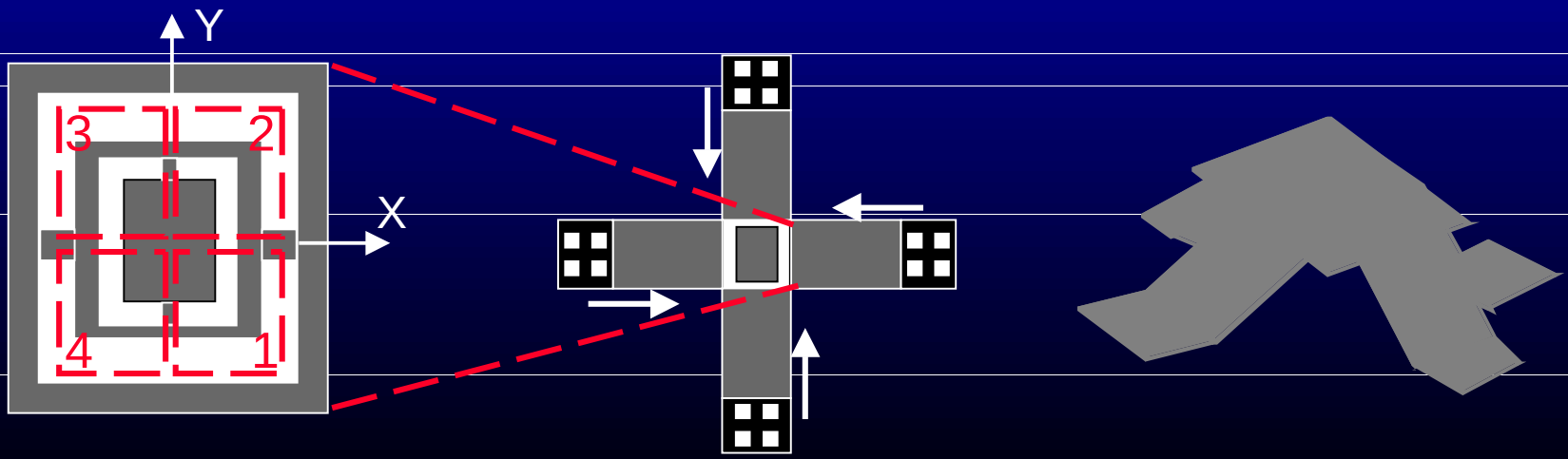
MEM Models

- Scratch Drive Acuator (SDA)



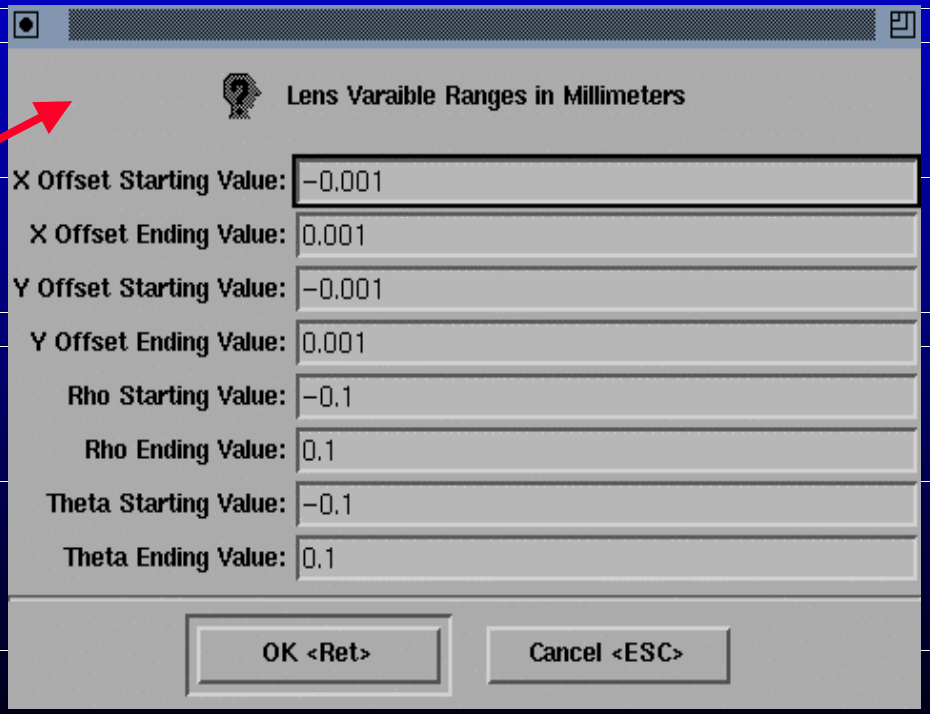


- Scanning Mirror on MESA Structure



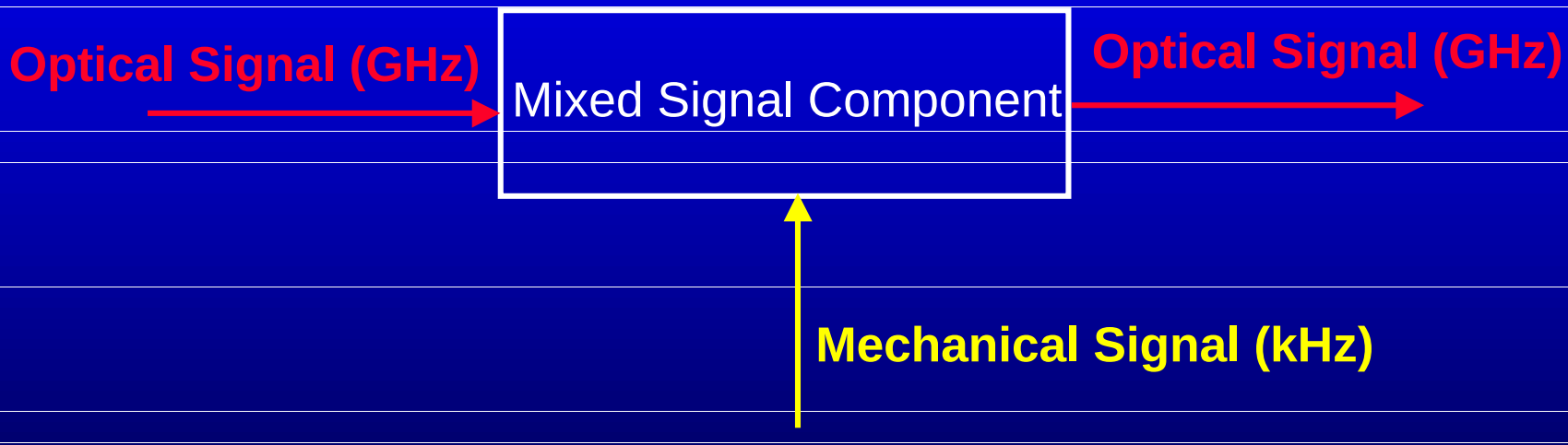
Monte Carlo Analysis

- Probability Distributions (Uniform, Gaussian) instead of Specific Component Values
- Run System Thousands of Times
- Analyze “best” and “worst” case results
- Sensitivity Analysis



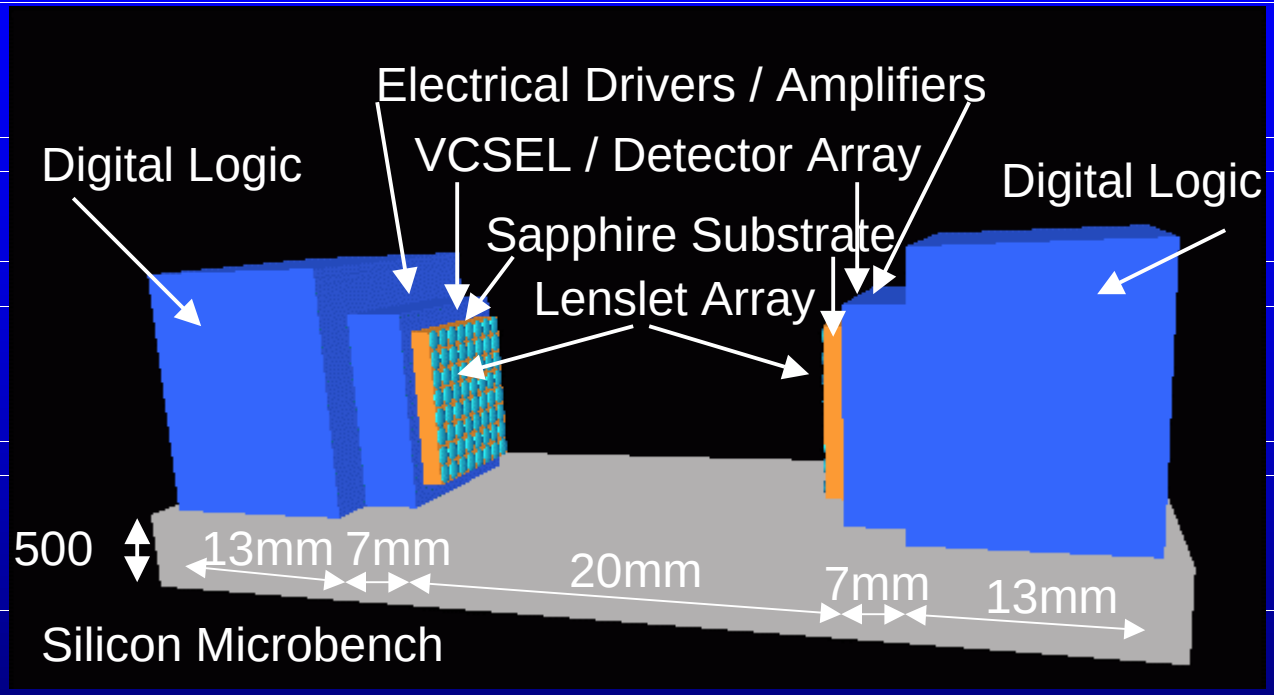
Scheduling for OMEM Mixed Domain

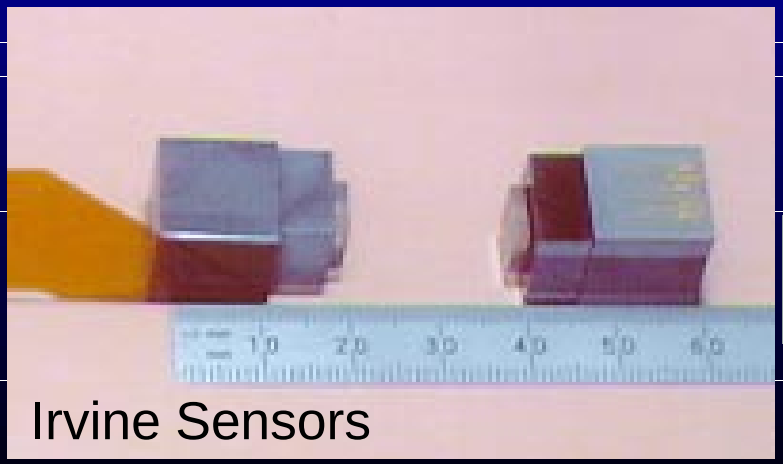
- Multi-rate Problems: Mixed Signal Component needs to compare arrival times and coordinate the interaction of the two signals

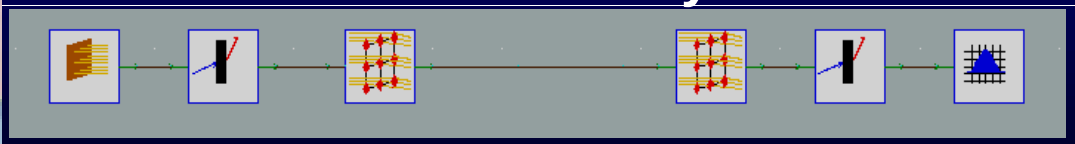


- Developed a *Adaptive Algorithm* within the DDF domain which adds sampling points when the accuracy tolerance is not met, and removes redundant sampling points during “steady state”

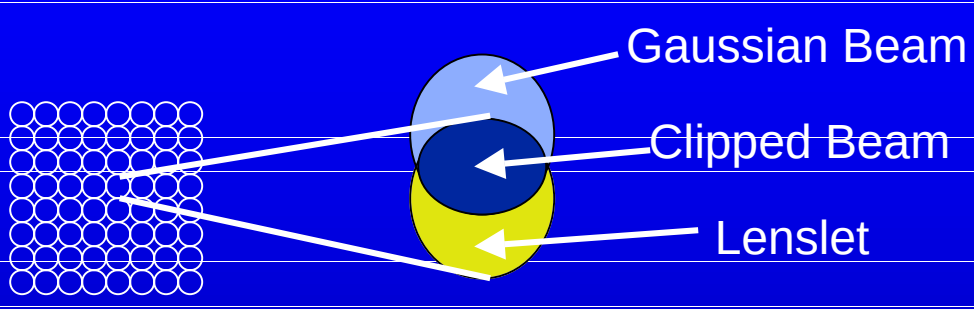
System 1: 3D OESP / FFT Design



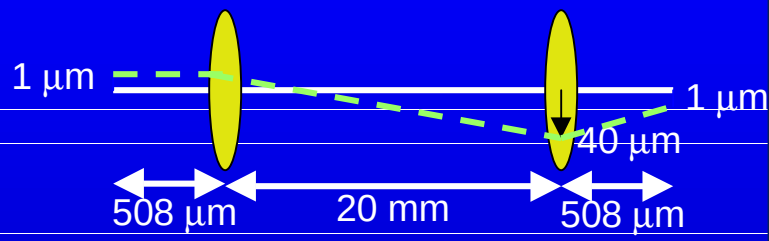




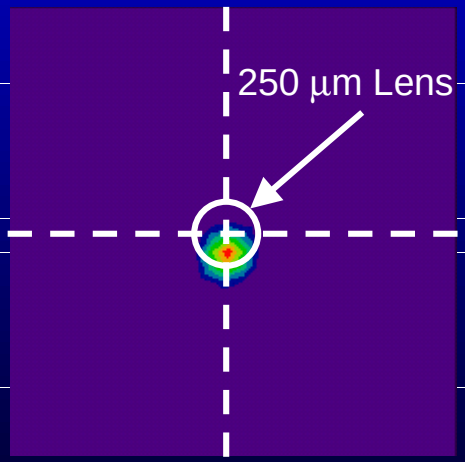
VCSEL 1 μm Mechanical Tolerancing - Scalar Analysis



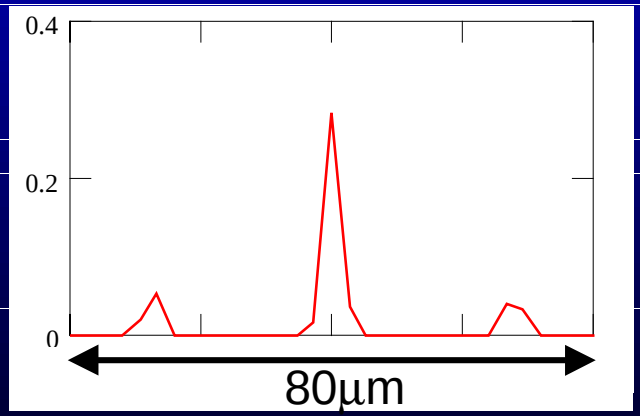
1 Lenslet of 8x8 Array



	1st Lenslet	2nd Lenslet	Total Loss
Mis-Aligned	4.53%	22.60%	26.10%
Aligned	4.53%	0.00%	4.54%



Intensity Distribution Contour
At 2nd Lenslet Plane



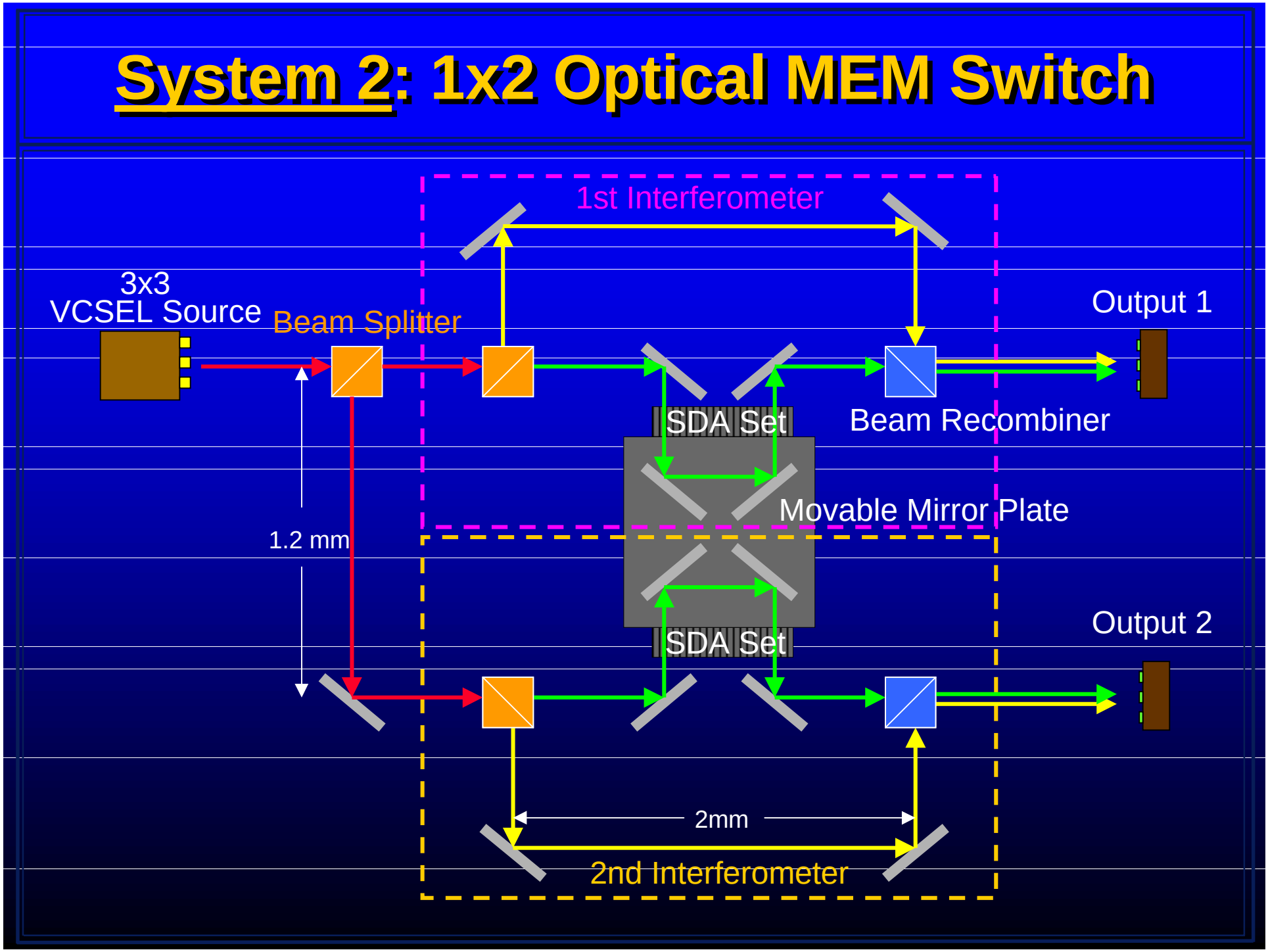
Final Intensity Distribution on
the 80mm detector

Monte Carlo Simulation

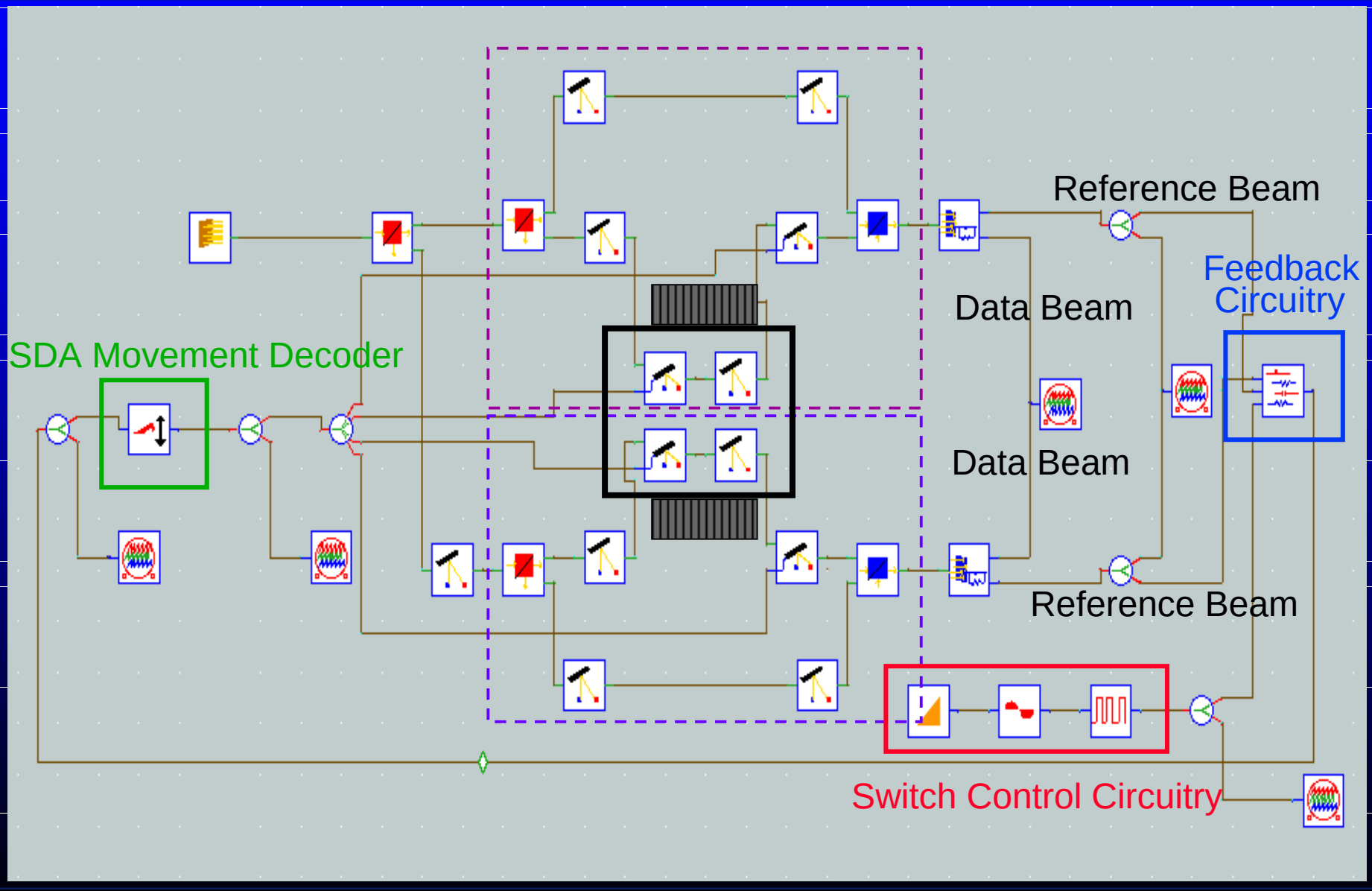
- 10,000 Simulations
- All parameters have Gaussian Distribution
- Table shows:
  - 2 cases with largest deviation in parameters, but detect full optical power
  - 2 cases where the parameters deviate the least, but result in the beam entirely missing the desired detector

Parameter	Lens1_x	Lens1_y	Lens1_r	Lens1_q	Lens2_x	Lens2_y	Lens2_r	Lens2_q	Detect_x	Detect_y
Demensions	mm	mm	degrees	degrees	mm	mm	degrees	degrees	mm	mm
Variance	1	1	0.05	0.05	1	1	0.05	0.05	1	1
Full Power #1	-0.607	-0.587	-0.056	-0.029	0.555	0.608	-0.036	0.029	-0.462	-0.954
Full Power #2	0.464	-0.393	0.015	-0.007	0.418	0.424	-0.012	-0.011	-0.392	0.685
No Power #1	0.395	1.167	-0.004	**0.007**	-0.409	-0.247	-0.004	0	-0.61	-0.897
No Power #2	-0.497	1.553	-0.009	0.004	0.991	0.349	-0.009	**-0.011**	0.223	0.448

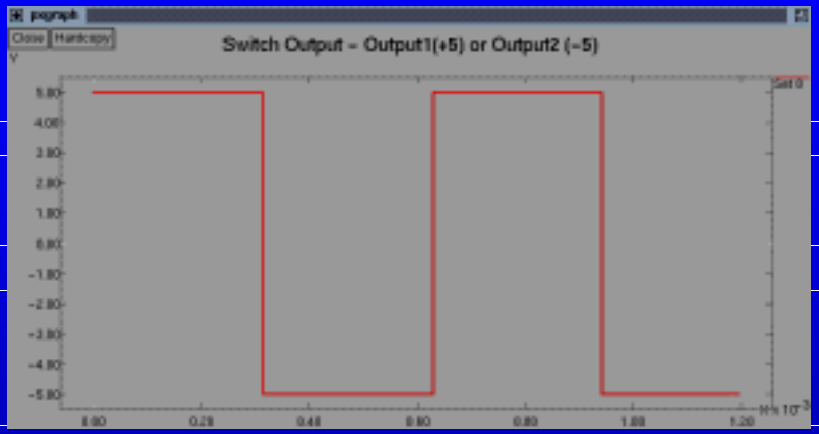
System 2: 1x2 Optical MEM Switch



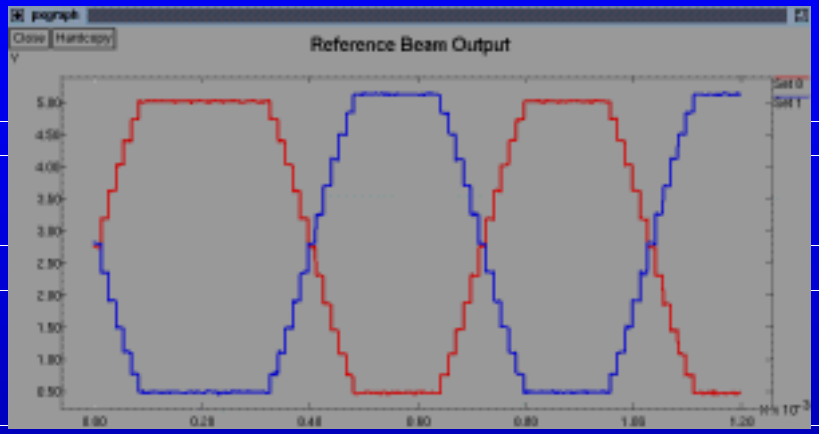
1x2 Optical MEM Switch in Chatoyant



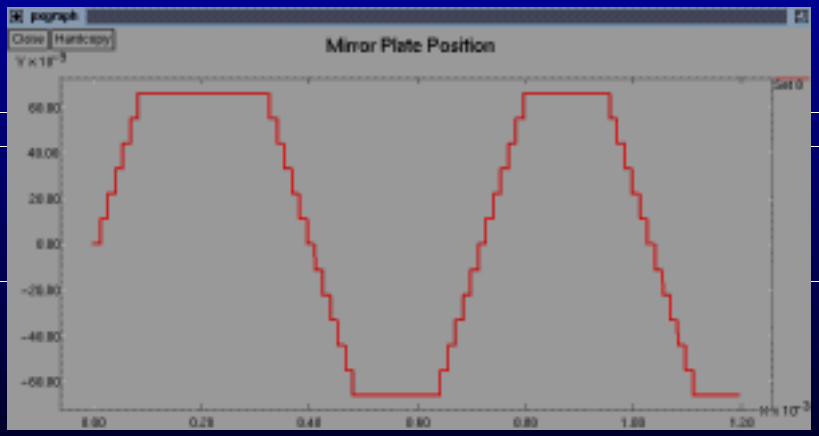
1x2 Switch Dynamic Outputs



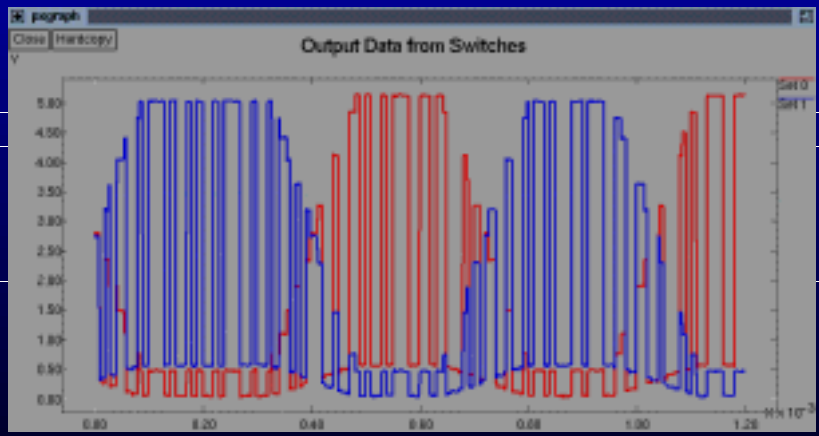
Switch Selection



Reference Beam

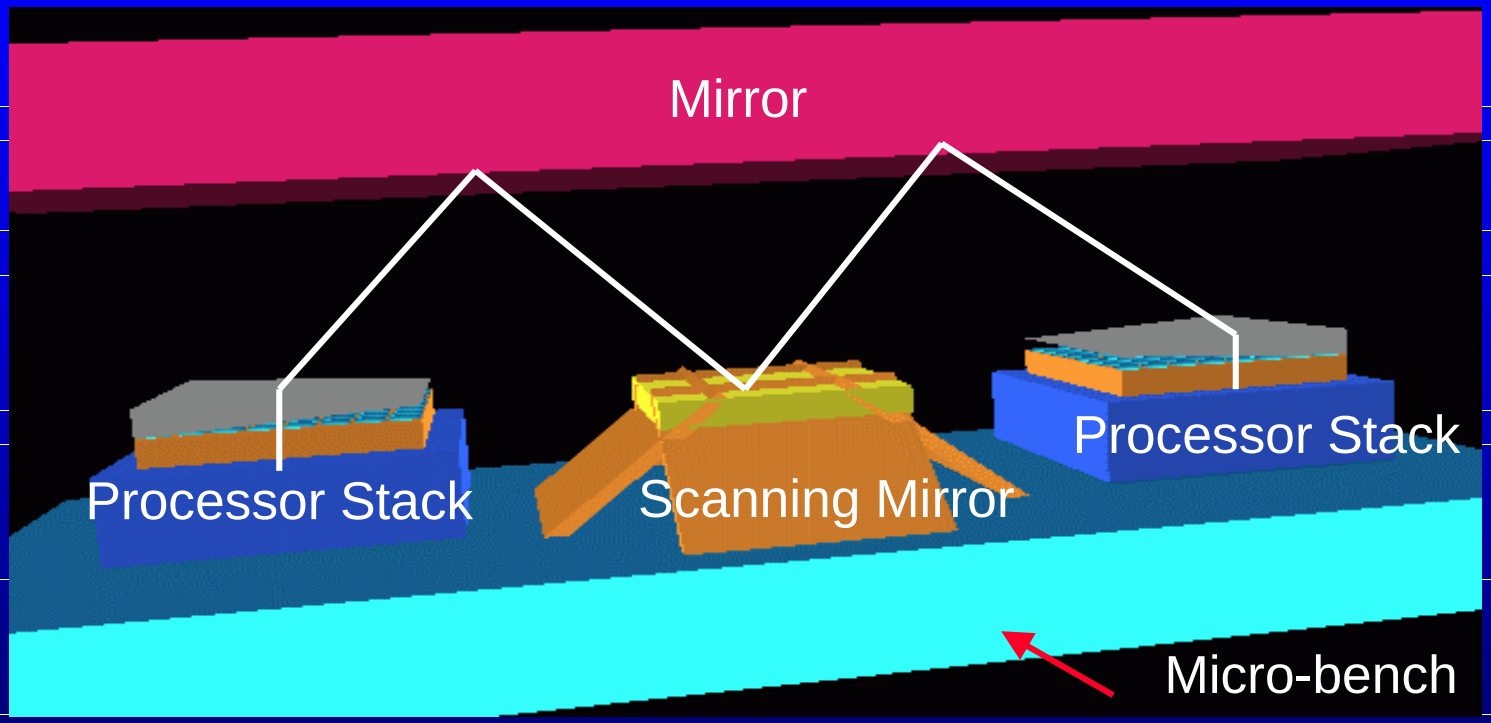


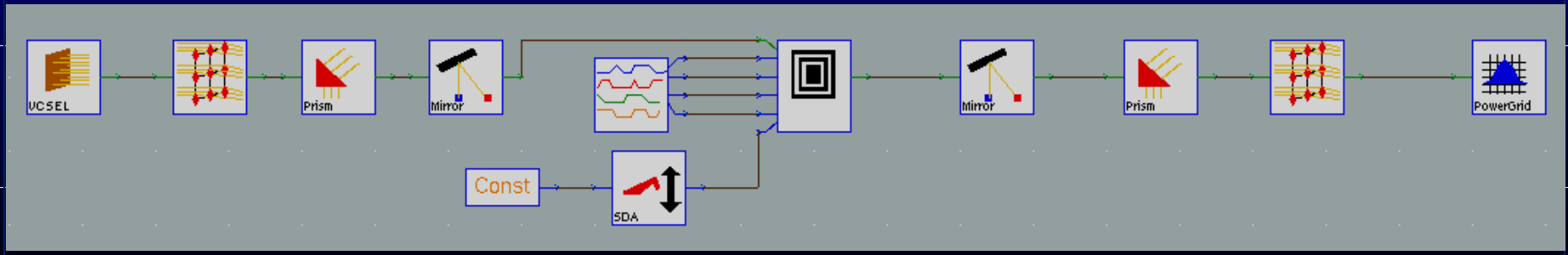
Mirror Position



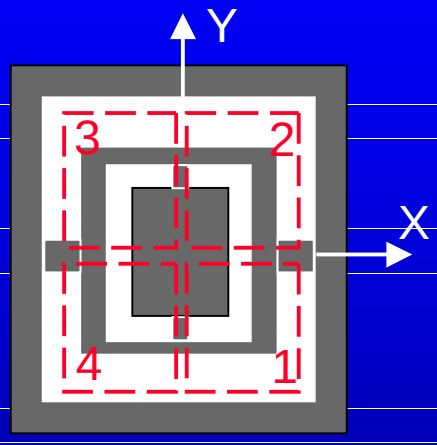
1x2 Switch Output

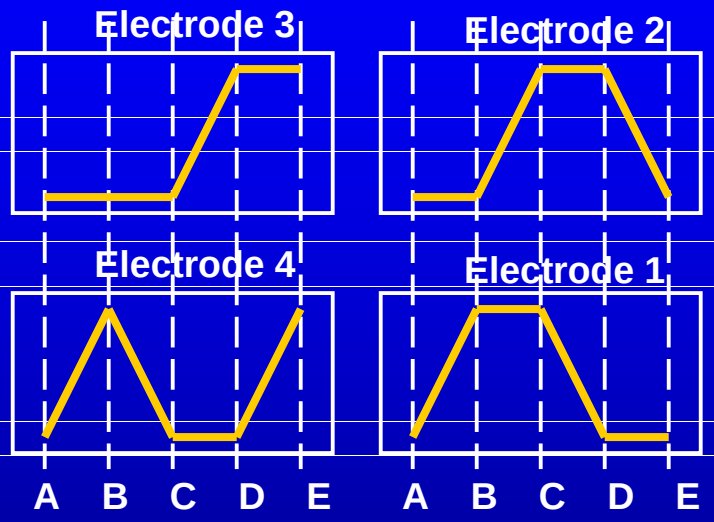
System 3: Beam Steering with Scanning Mirror

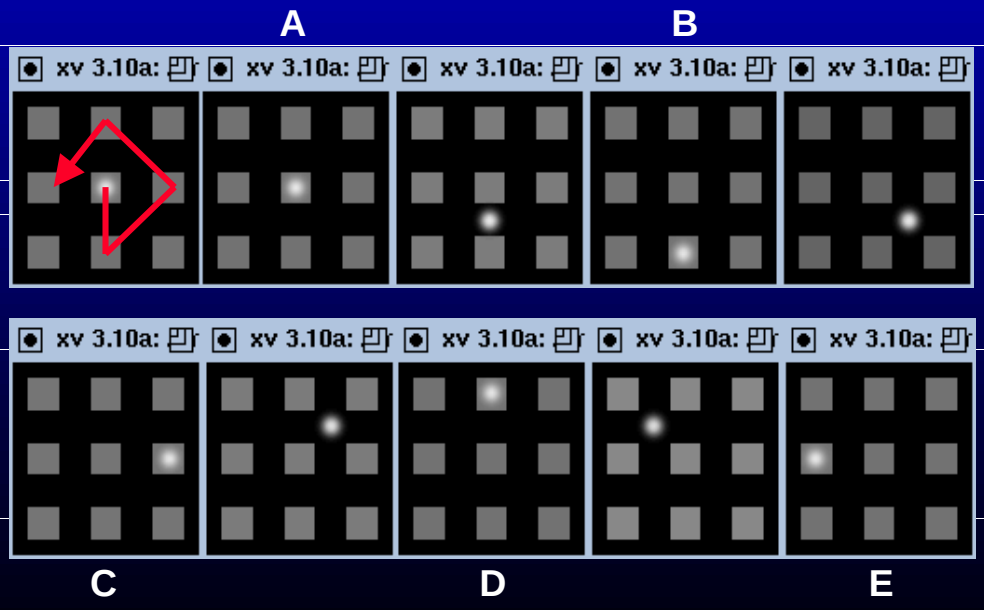




Scanning Mirror Simulations







Conclusions

- CAD is needed for optical MEMS
- Challenging to create - Mixed technology/domains
  - Optical, Electrical, and Mechanical
- Chatoyant can be extended to model, simulate, and analyze optical MEM systems
- Chatoyant advantages:
  - performs trade-offs
  - quick efficient analysis
  - reduce costly prototyping