Mixed-Technology System-Level Simulation

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Funding DARPA: F30602-97-2-0122 / NSF: ECS 96-16879

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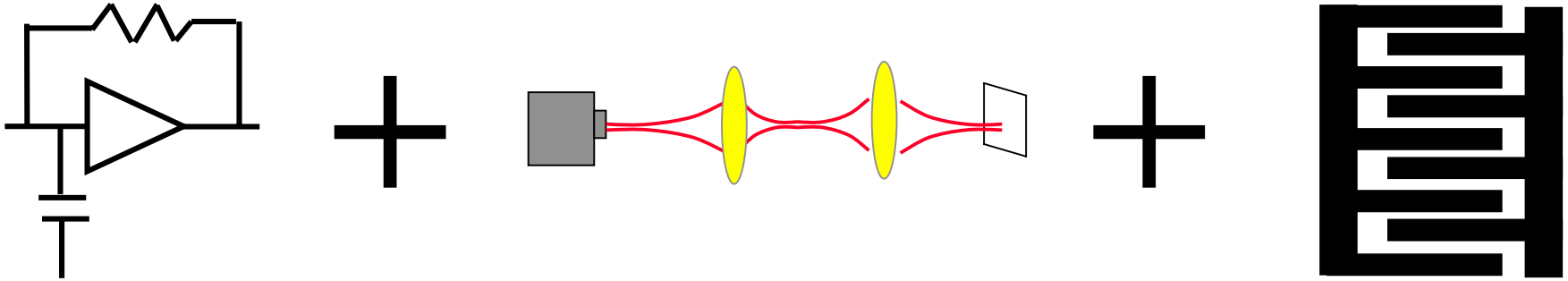
Outline

- Motivation: Mixed-Signal CAD
- Overview of *Chatoyant*
- Signal Models
  - Electrical/Opto-electronic
  - Mechanical
- Example Systems
- Conclusions & Future Work

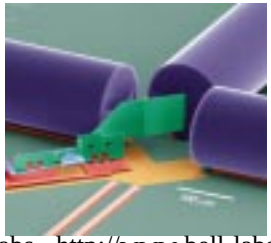
Mixed-Signal Technology



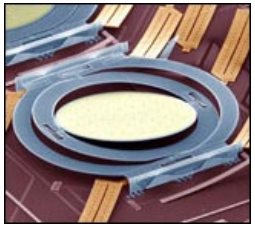
- **Electronics**
- **Optics**
- **Micromechanics**

Telecommunications

Switches, Modulators, Attenuators, Equalizers



Bell Labs- http://www.bell-labs.com/



Lucent - http://www.lucent-optical.com/

Sensing

Chemical, Thermal, Inertial

Thick-Film PZT Sensing Element University of Southampton Institute of Transducer Technology - http://www.usitt.ecs.soton.ac.uk/

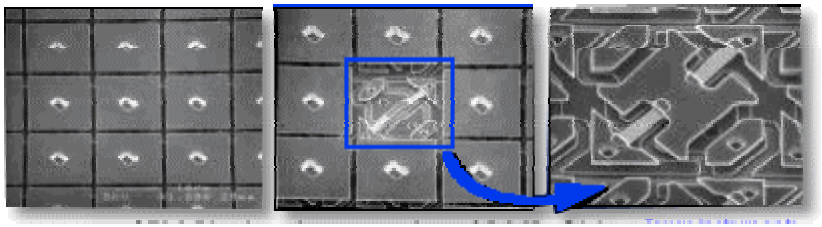
Optical Computing

Data Storage, Backplanes, Interconnects

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

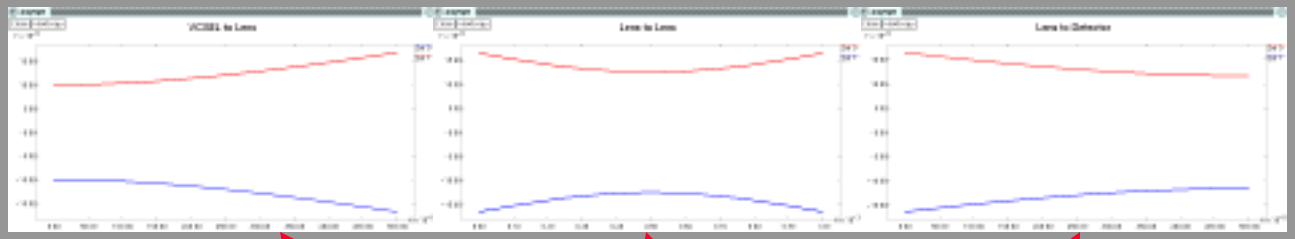
Imaging

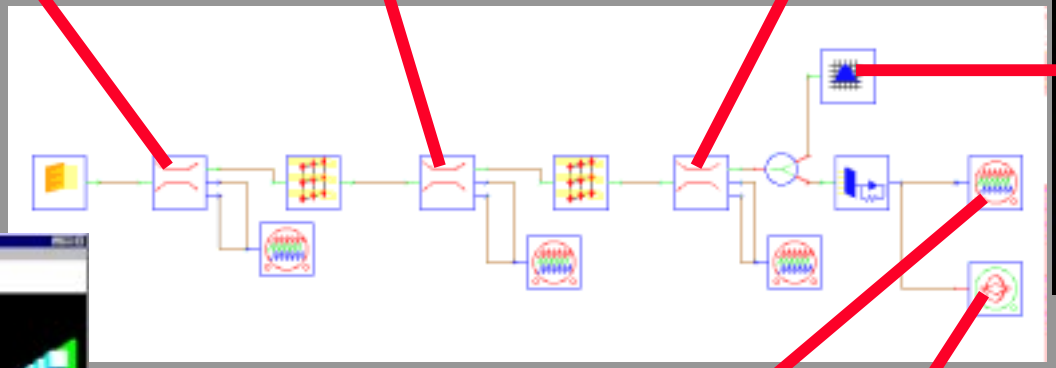
Scanning, Display, Printing, Adaptive

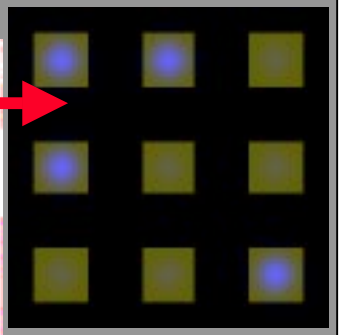


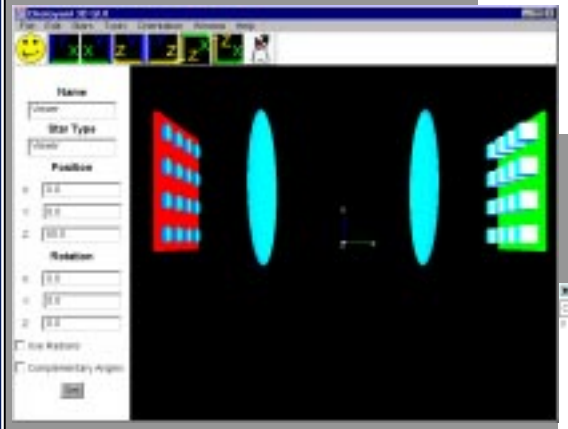
Texas Instruments - DMD - From Darpa
http://www.darpa.mil/ETO/MOEMS/DMD/index.html

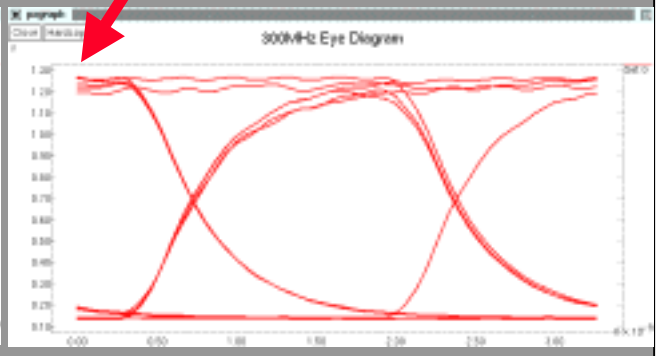
Chatoyant



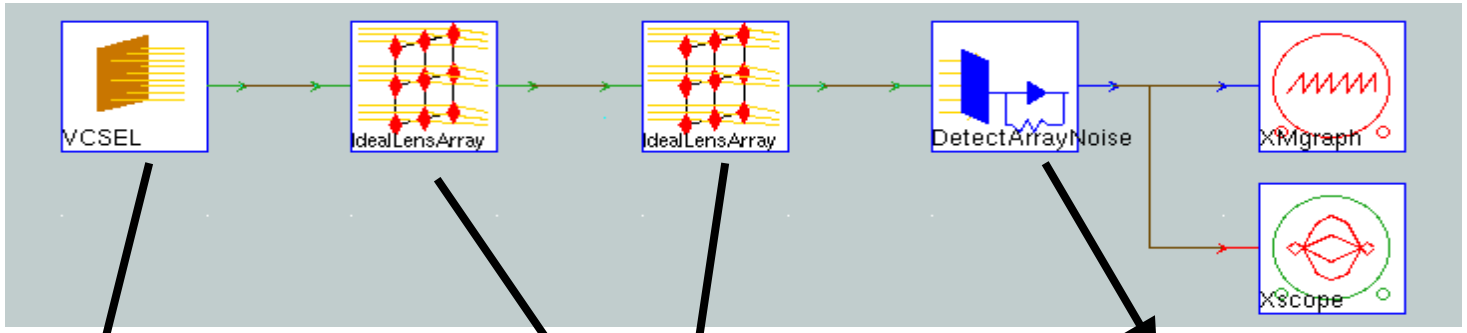




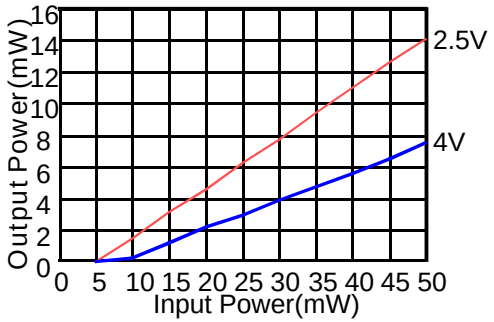




Component Models



- **Empirical models**
  - **Experimental data fitting**

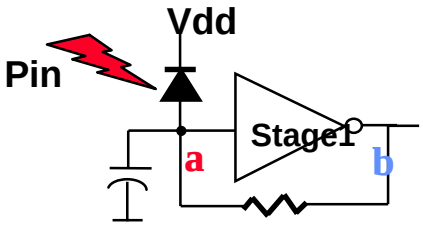


$$P_{out} = \frac{\eta_{LI}/V_{th}}{(1-\eta_{LI}/V_{th})}(P_{in} - I_{th}V_{th})$$

- **Analytic models**
  - **Physics based**

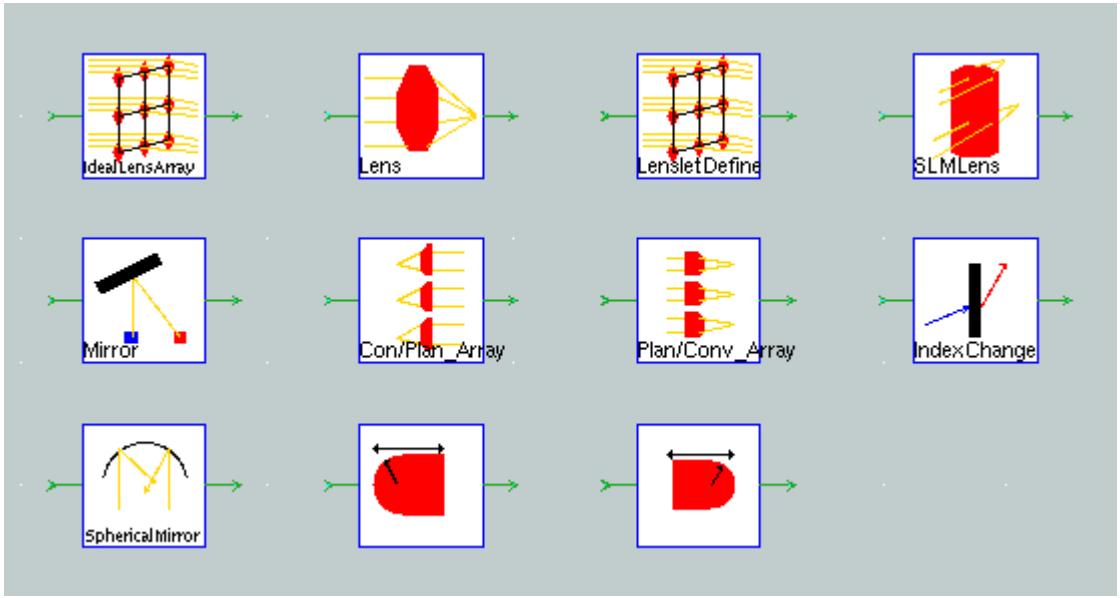
$$I(r,z) = I_0\left[\frac{W_0}{W(z)}\right]^2 \exp\left[-\frac{2r^2}{W^2(z)}\right]$$

- **Derived models**
  - **Parametric models extracted from or verified by lower level tools**



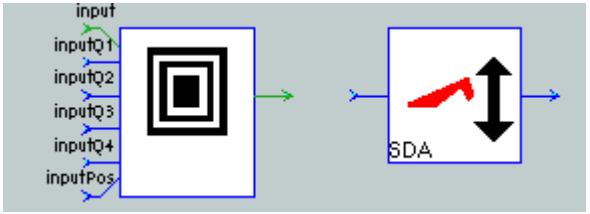
$$V_0(s) = \frac{R_f}{1+\left(\frac{R_f C}{A}\right)s} \cdot P_{optic}(s)$$

Chatoyant's Libraries

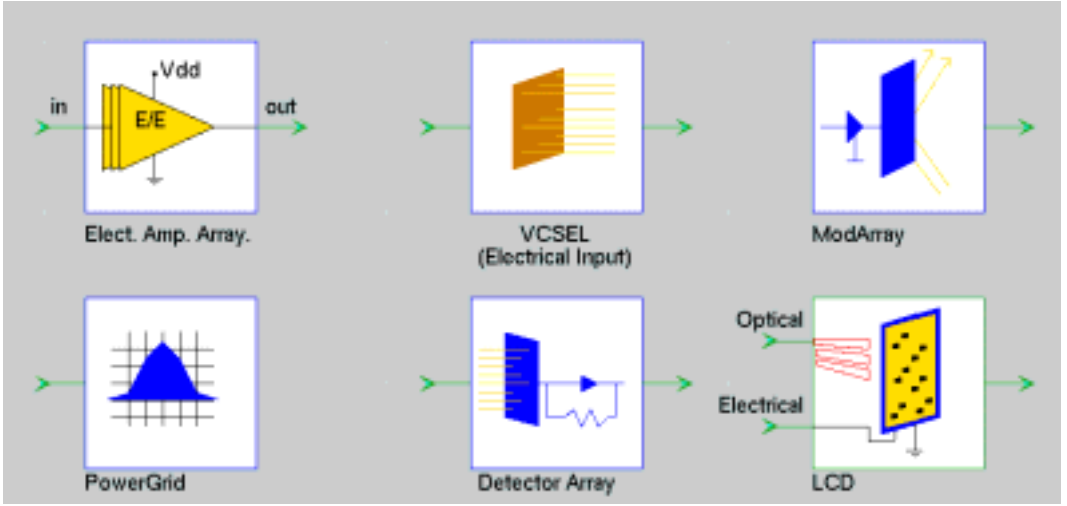


Optical Library

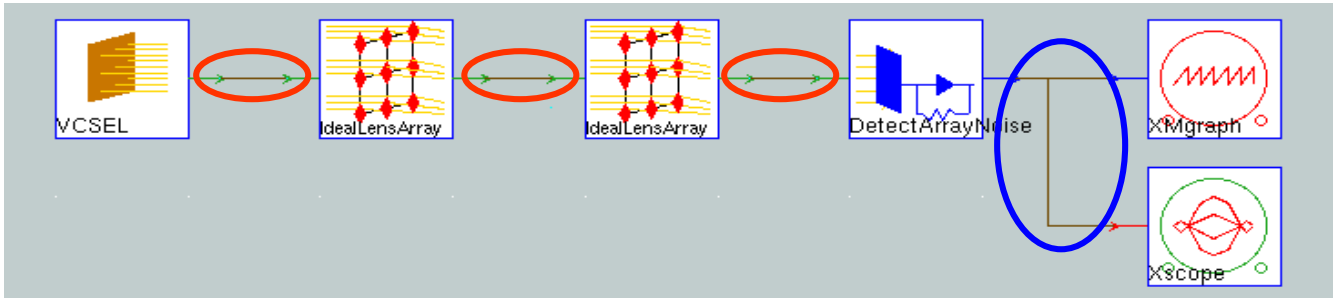
Mechanical Library



Optoelectronic Library

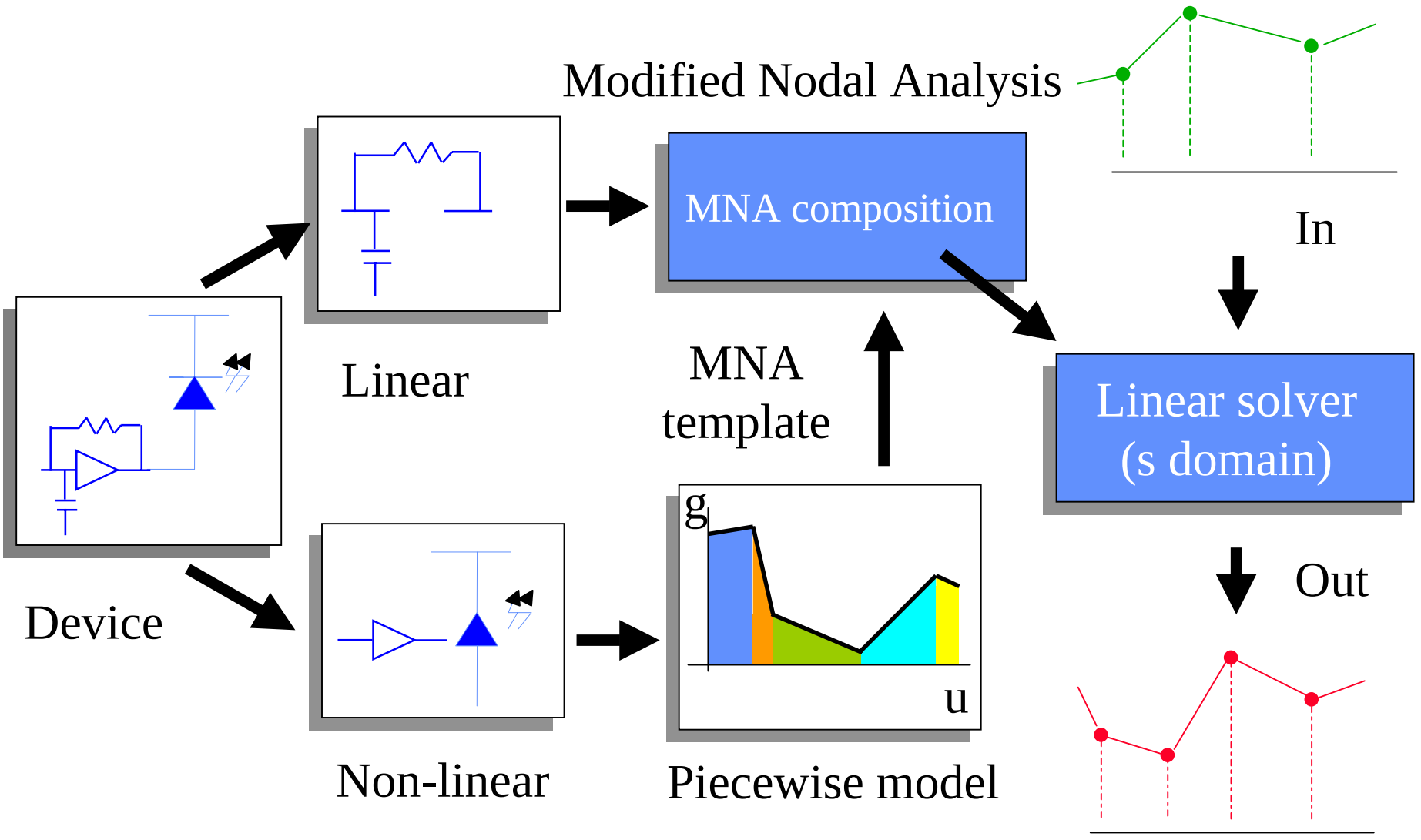


Message Class



- Heterogeneous interface for transmission of data information between components
- Supports electrical & optical signals and Δ time between particles
- Electrical:
  - Voltage and impedance matching parameters, C_{sb} and g_{sb}
- Optical:
  - x, y, ρ, θ, λ, intensity, z0, zw0, phase
  - gridded diffractive wavefront

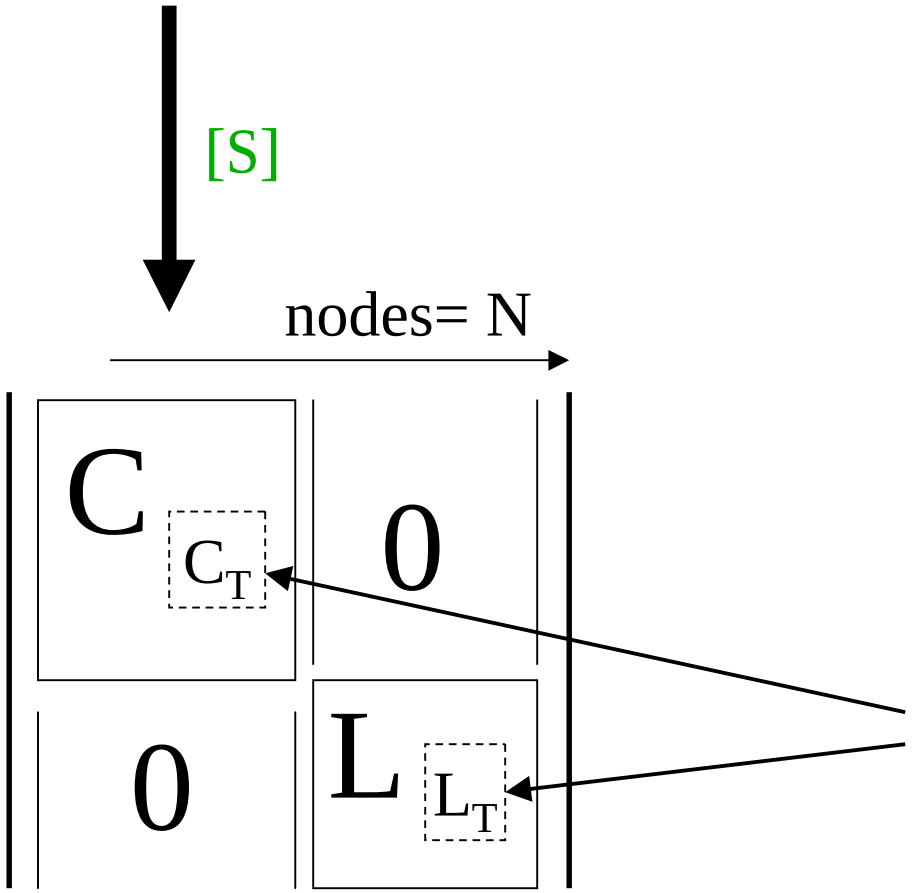
Piecewise Solver



MNA Composition

Modified Nodal Matrix representation:

$$[S][x'] = -[G][x] + [B][u]; \quad [I] = [B^T][x]$$



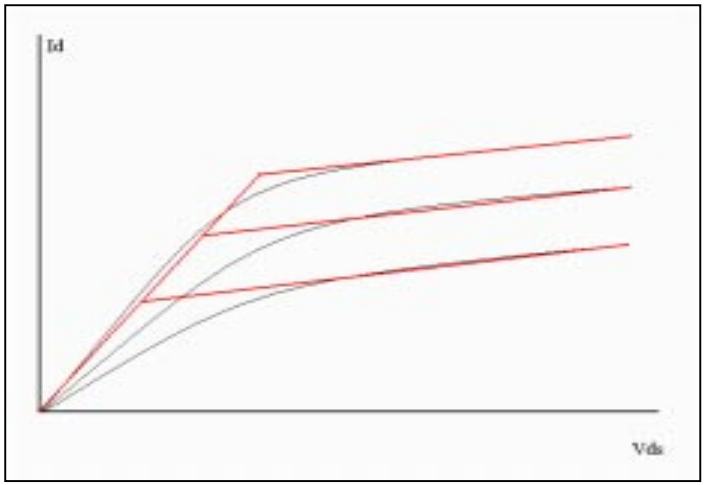
[S] Storage element matrix
[G] Conductance matrix
[x] State variables
[B] Connectivity matrix
[u] Excitation vector
[I] Current vector.

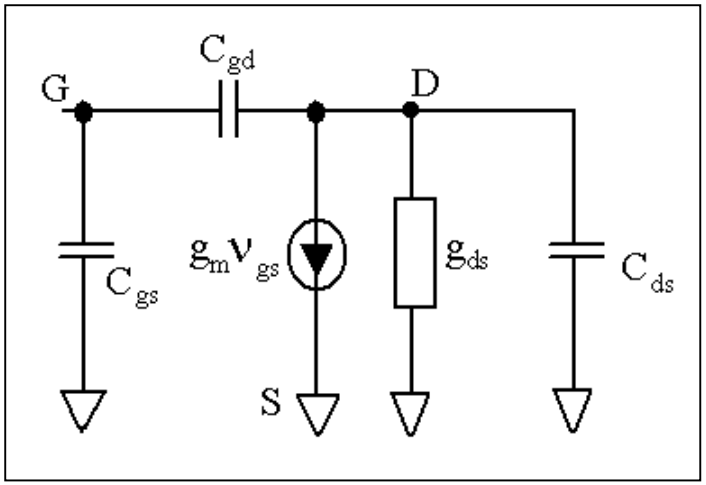
$[S]_T$ Template from a *bounded* non-linear element (i.e., nodes <N)

Template for a MOSFET

$$S=\begin{bmatrix}(C_{gd}+C_{ds}) & -C_{gd} & -C_{ds}\\ -C_{gd} & (C_{gd}+C_{gs}) & -C_{gs}\\ -C_{ds} & -C_{gs} & (C_{gs}+C_{ds})\end{bmatrix};\ G=\begin{bmatrix}gds & gm & (-gds-gm)\\ 0 & 0 & 0\\ -gds & -gm & (gds+gm)\end{bmatrix};\ B=\begin{bmatrix}0 & 0 & 0\\ 0 & 0 & 0\\ 0 & 0 & 0\end{bmatrix}$$

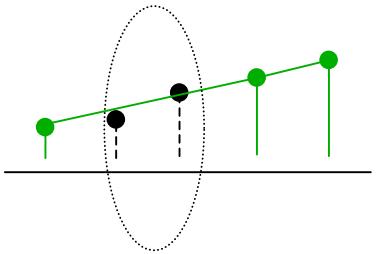
- ***gds*** is the conductance at the output port
- ***gm*** is the transconductance
- C_{gd},C_{gs} & C_{ds} are the parasitic capacitances in the MOS



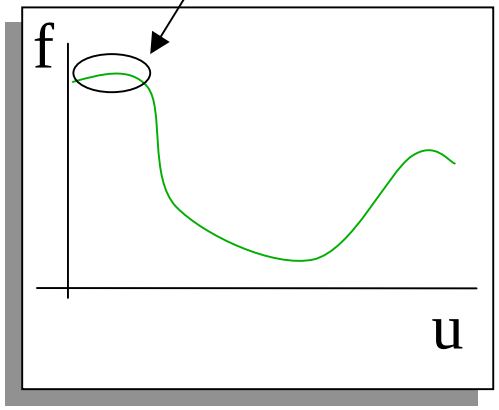


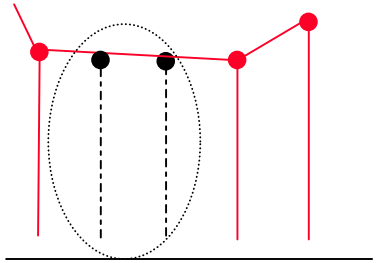
Dynamic Sampling Control

Can undersample



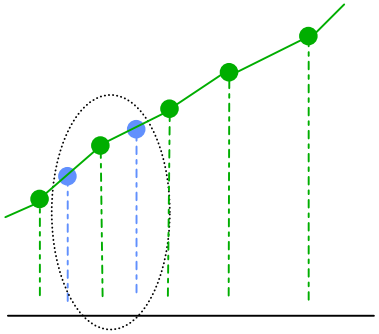
In A



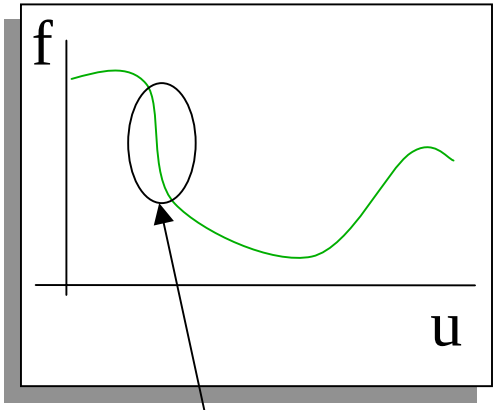


Out A

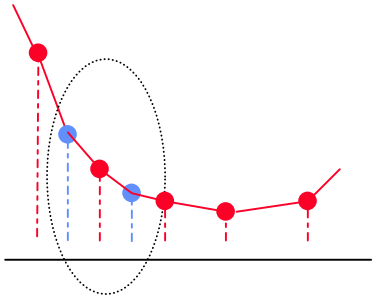
Must oversample



In B

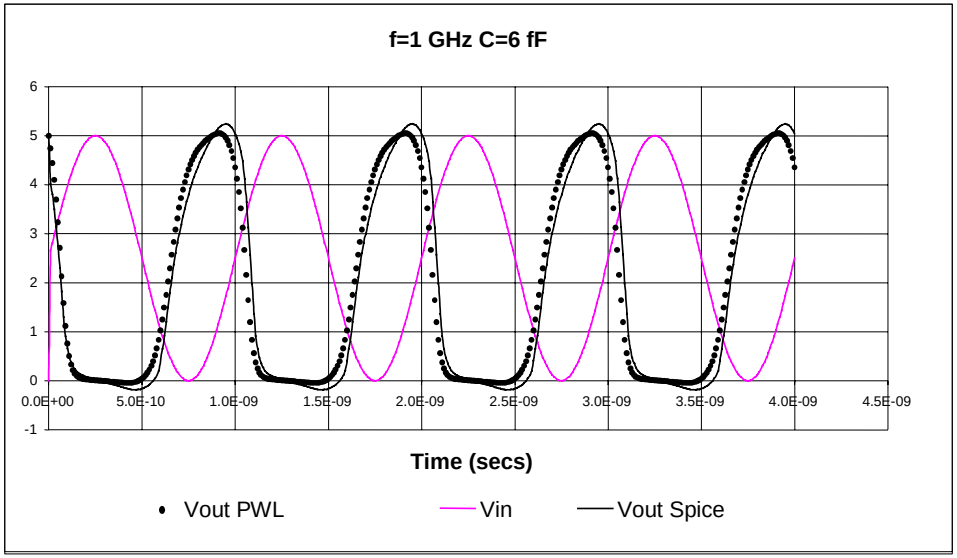


fast transition



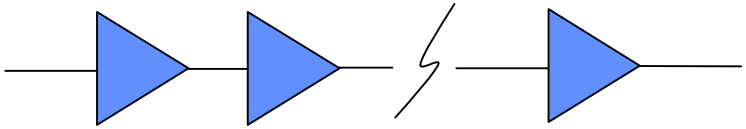
Out B

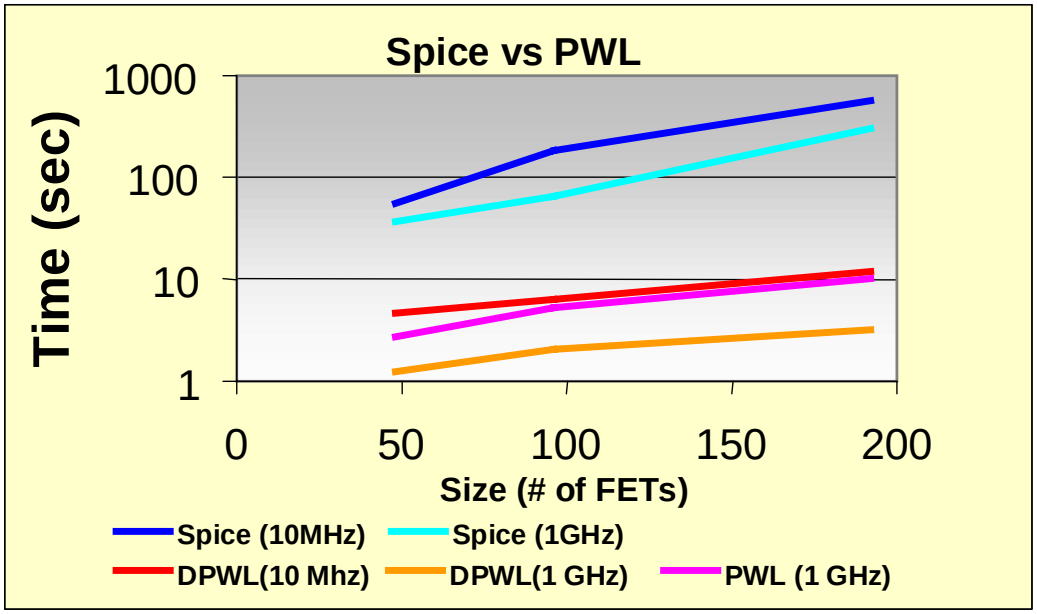
PWL Simulations



PWL and Spice output for inverter under capacitive load and frequency of 1GHz

Spice vs. PWL and DPWL models in a system of multiple FETs





Mechanical Modeling

- Same PWL technique as in electrical modeling
- General motion equation for a mechanical structure:

$$F = [K][U] + [B][\dot{U}] + [M][\ddot{U}]$$

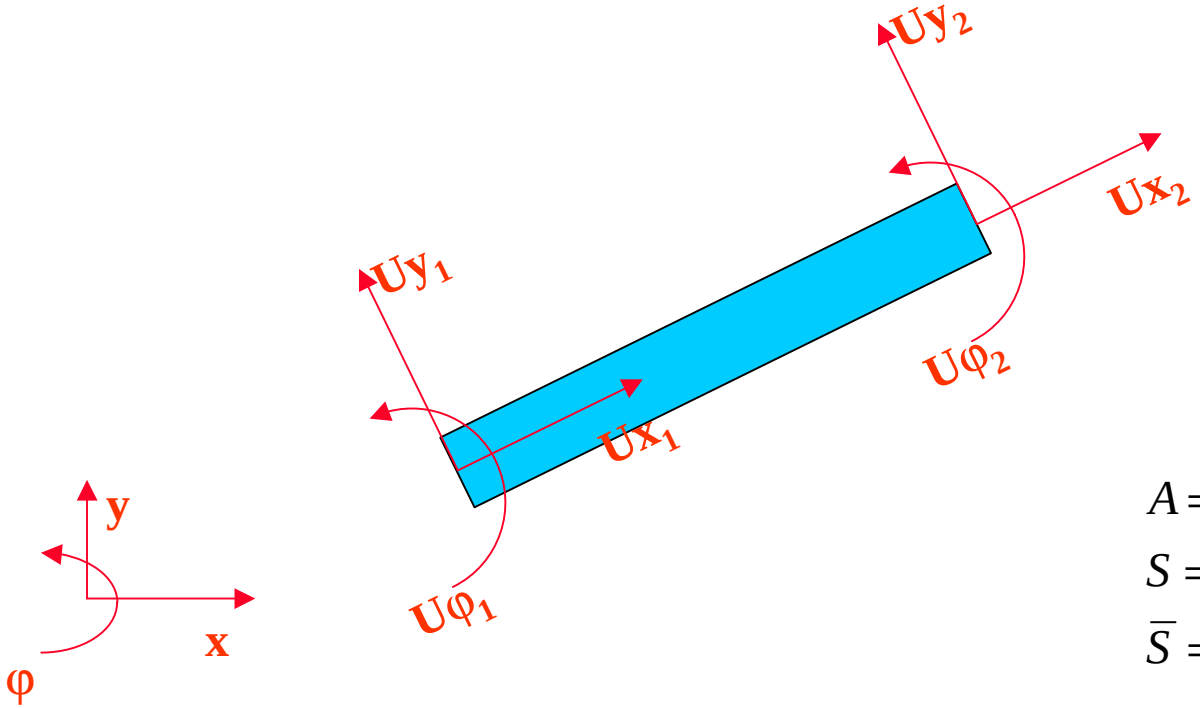
- Reduction to standard ODE form:

$$\begin{bmatrix} 0 & M \\ M & B \end{bmatrix} \begin{bmatrix} \ddot{U} \\ \dot{U} \end{bmatrix} + \begin{bmatrix} -M & 0 \\ 0 & K \end{bmatrix} \begin{bmatrix} \dot{U} \\ U \end{bmatrix} = \begin{bmatrix} 0 \\ I \end{bmatrix} F$$

$$[Mb]\dot{X} + [Mk]X = [\mathrm{E}]F \qquad \mathrm{X} = \begin{bmatrix} \dot{U} \\ U \end{bmatrix}$$

Mechanical Modeling

- Templates for every basic element (e.g. beam)
- Translation from local to global reference:



$$S = A^T \bar{S} A$$

A = Translation matrix

S = Global Matrix (M, K)

$\bar{S}$ = Local Matrix (M, K)

- Piecewise linear solver over global MNA representation

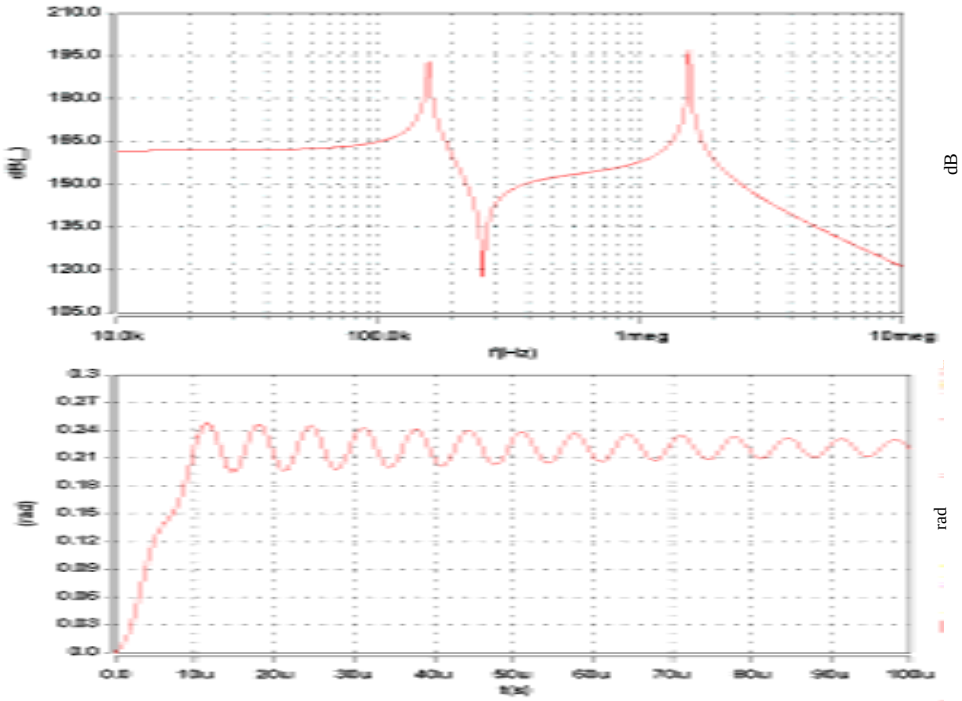
Template for the Constrained Beam

$$K = \frac{EI_z}{l^3}\begin{bmatrix} \frac{Al^2}{I_z} & 0 & 0 \\ 0 & 12 & -6l \\ 0 & -6l & 4l^2 \end{bmatrix}; \quad M = \frac{\rho Al}{420}\begin{bmatrix} 140 & 0 & 0 \\ 0 & 156 & -22l \\ 0 & -22l & 4l^2 \end{bmatrix}; \quad B = \delta\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix};$$

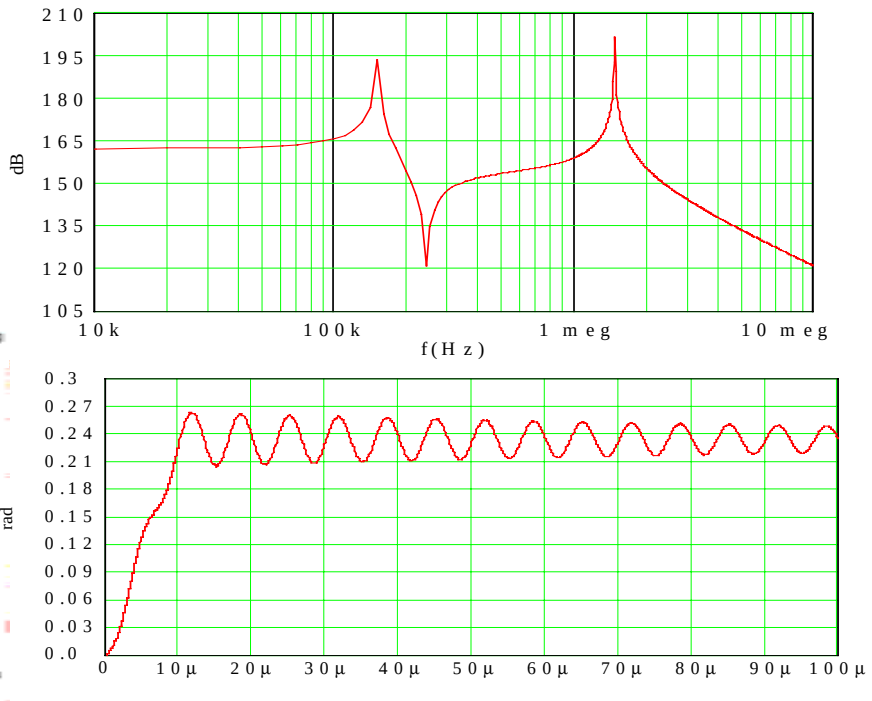
- E is Young's modulus
- I_z is the inertia momentum in z
- A is the area of the beam
- l is the length
- ρ is the density of the material
- δ is the viscosity factor acting over x and y components

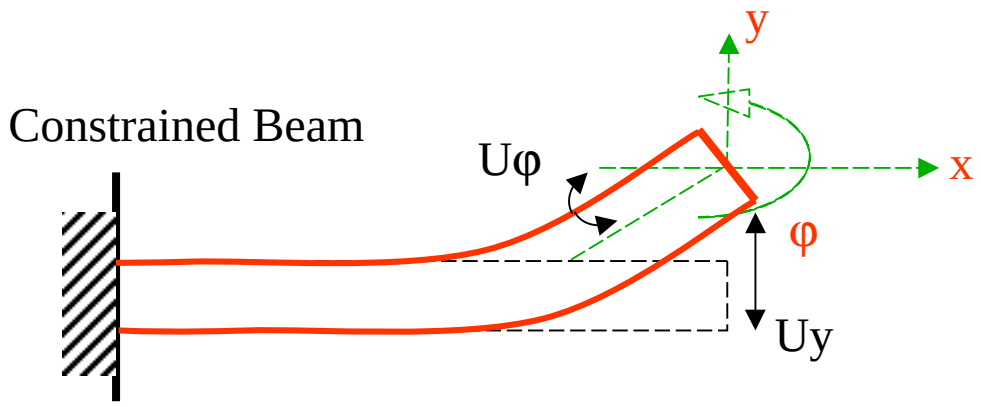
Frequency and Transient Response (φ)

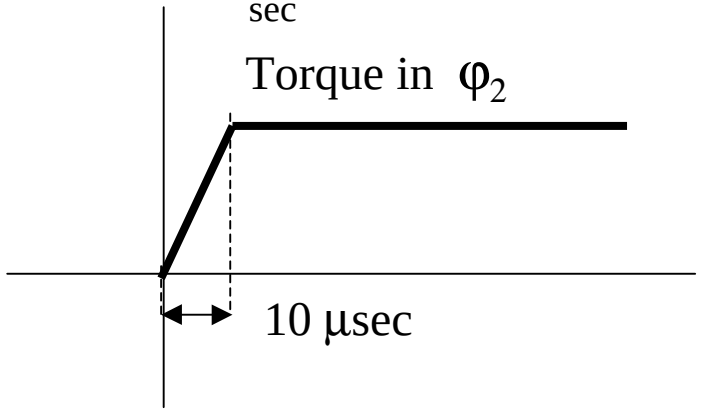
NODAS/SABER



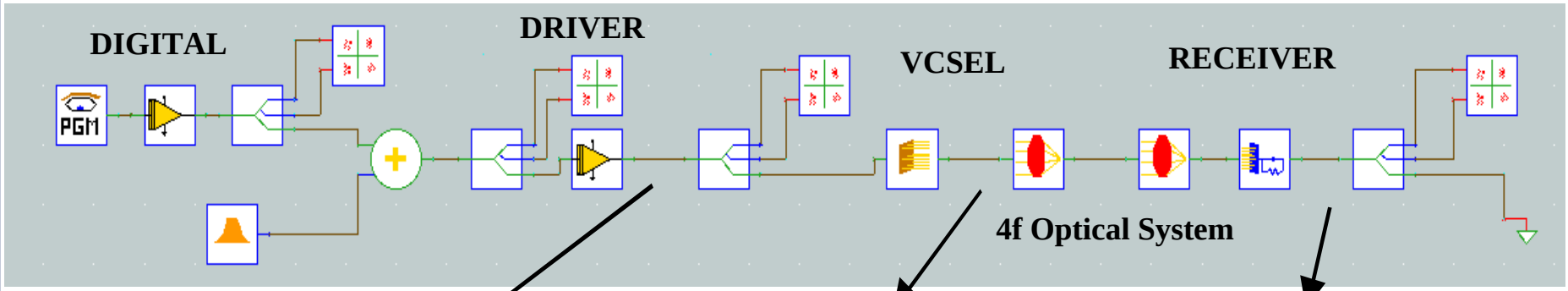
Chatoyant

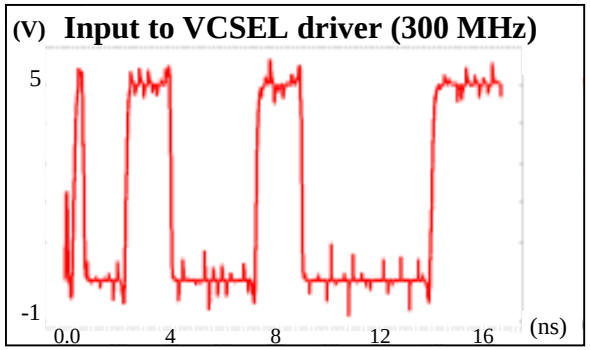


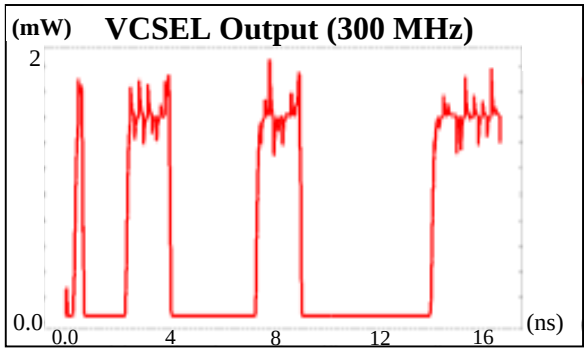


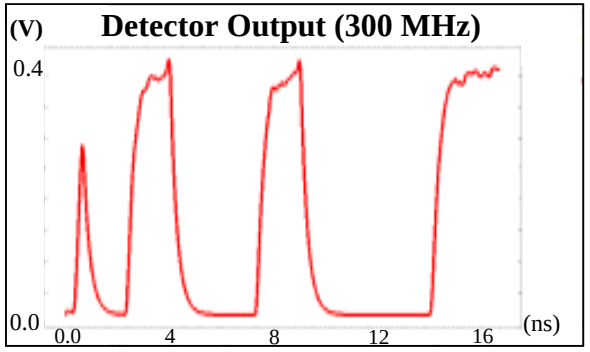


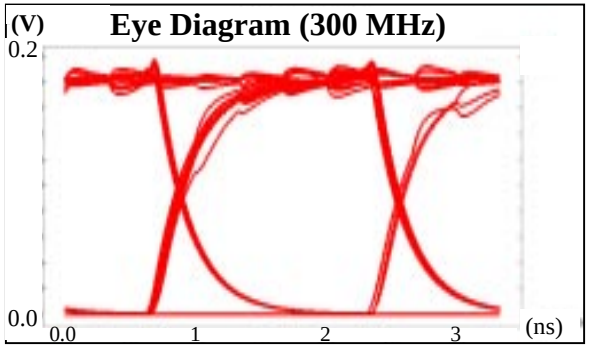
4f Free Space Optoelectronic Link

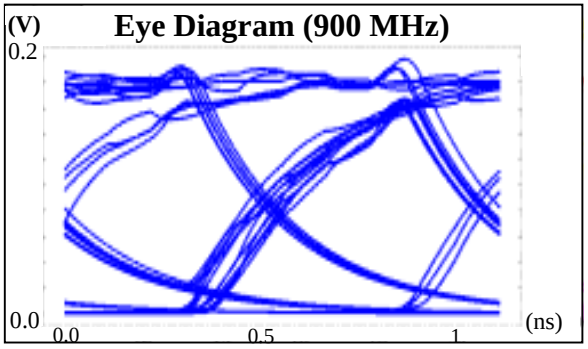


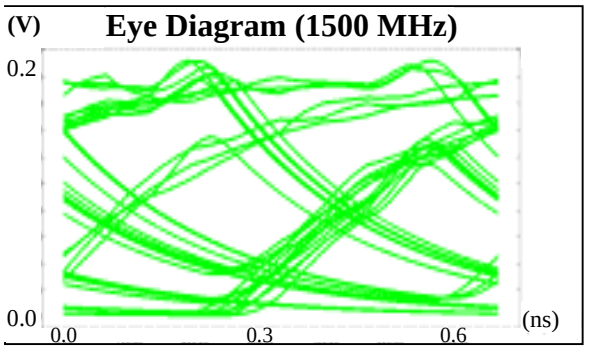




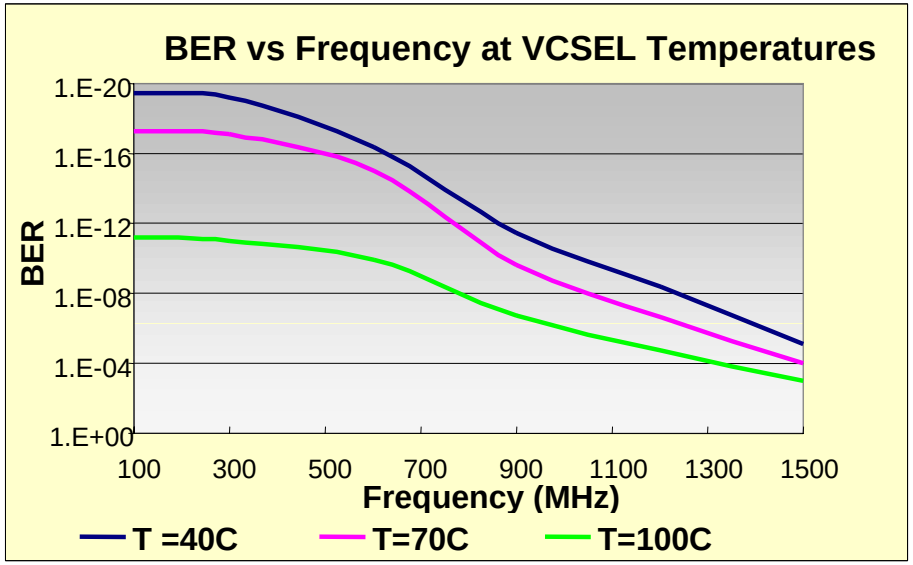


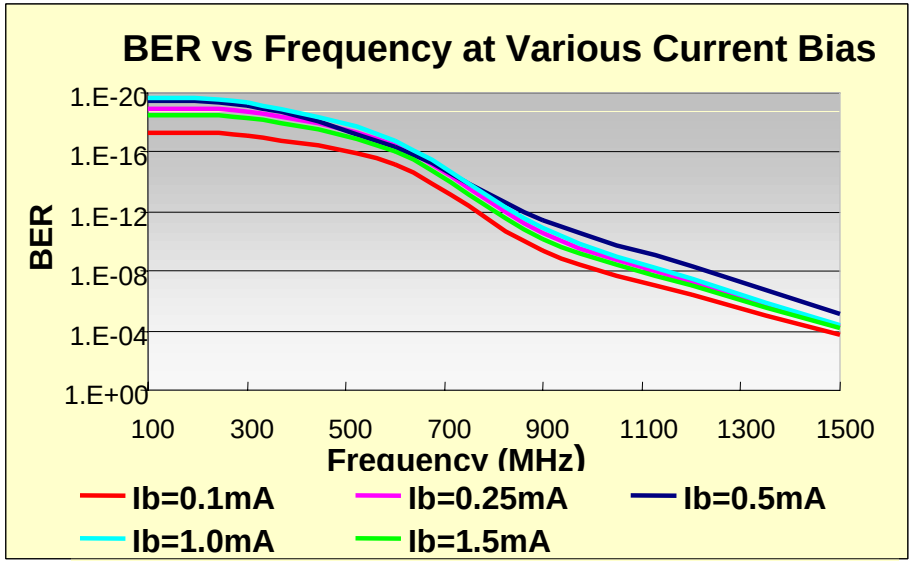


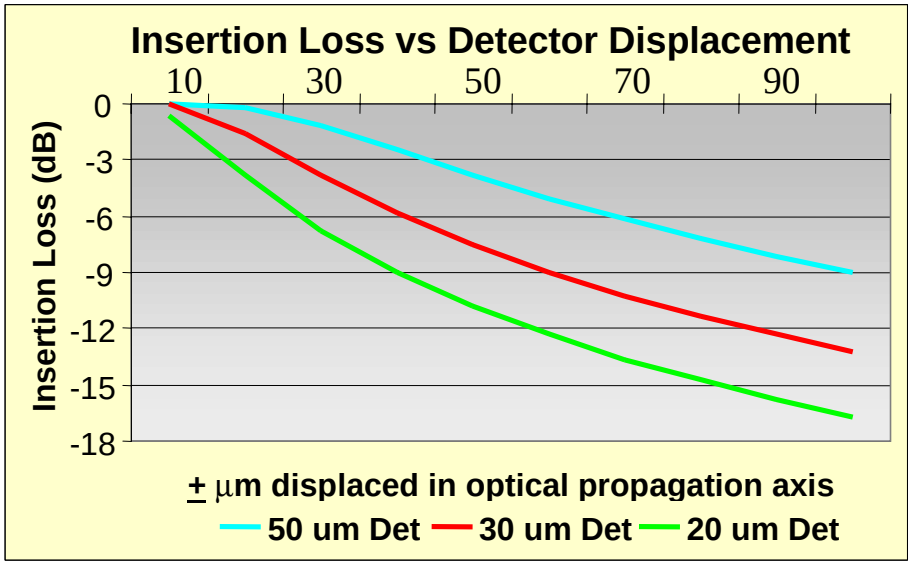


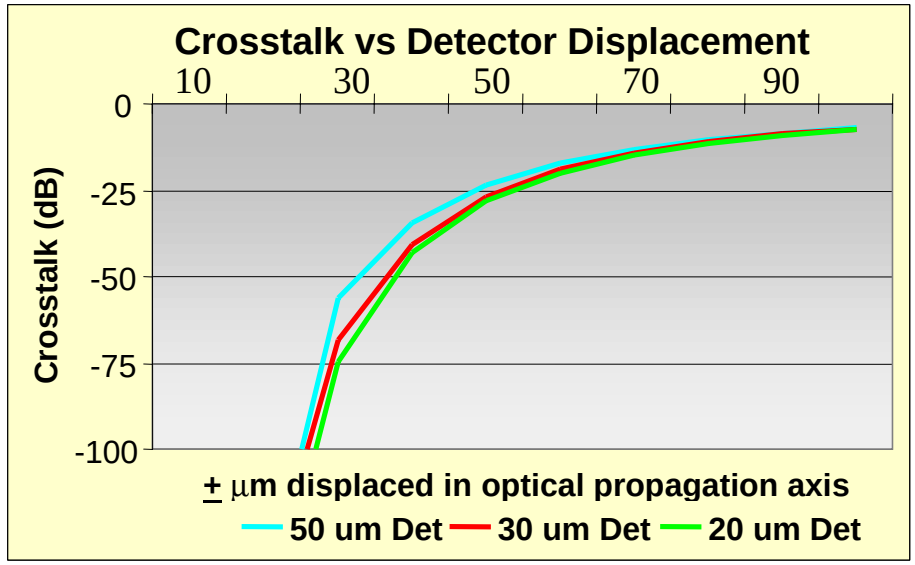


Performance Analysis

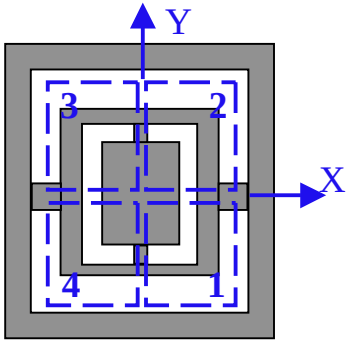


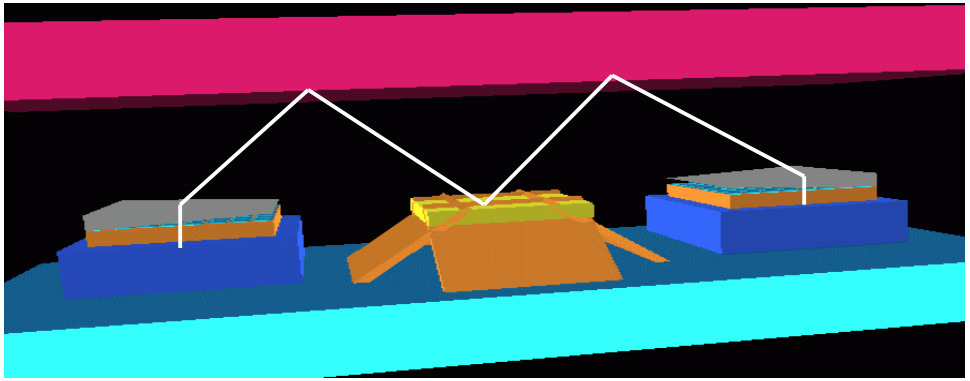


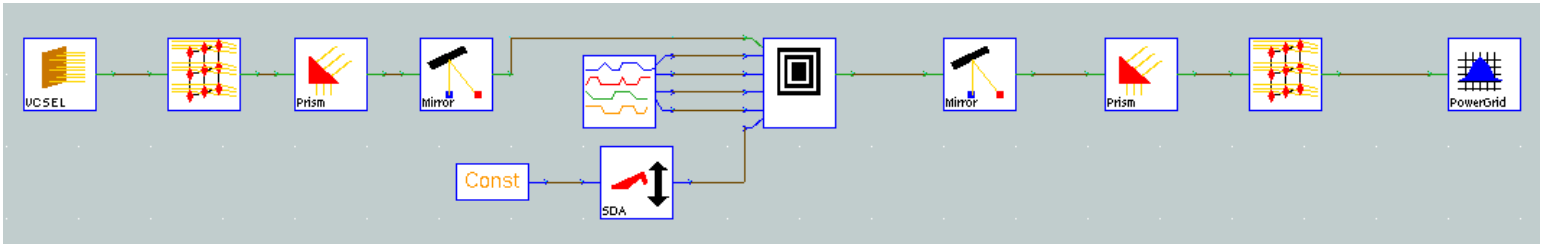


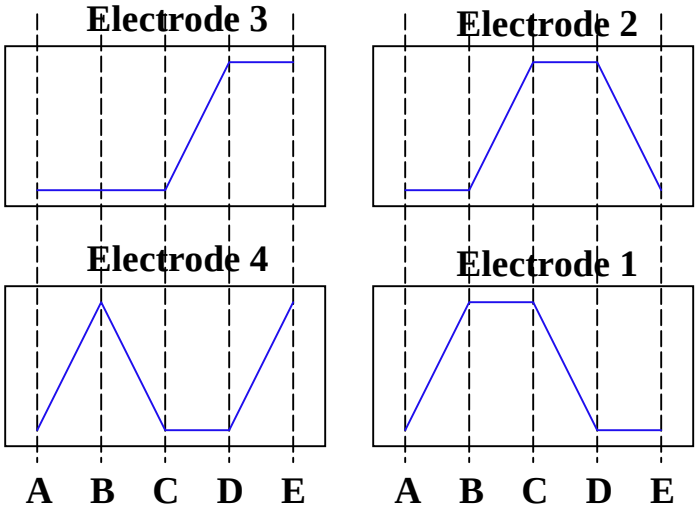


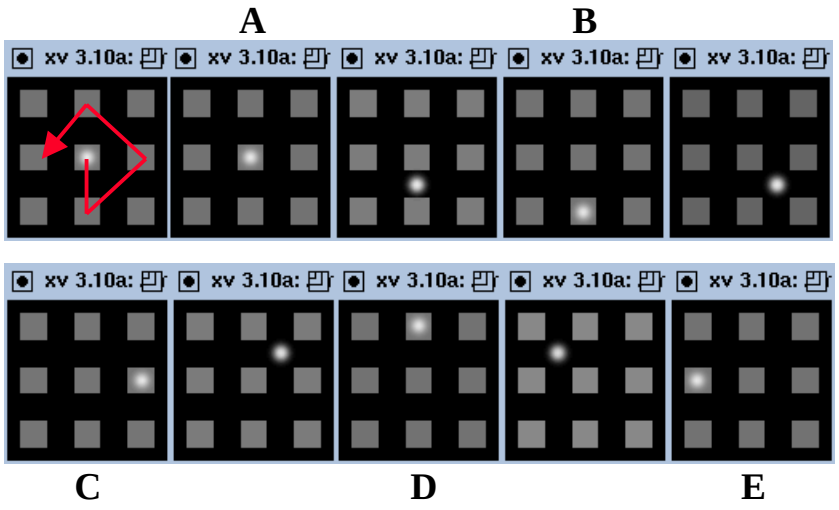
Beam Steering with Scanning Mirror











Conclusions

- CAD is needed for modeling mixed-domain systems
- PWL technique & matrix representation
  - Effective alternative to costly numerical integration
  - Integration in a multi-domain environment
  - Accuracy vs. speed trade-off
  - 1 to 2 orders of magnitude improvement on performance
- It is both desirable and possible to have device level behavior included in component models
- Allows the designer to use system-level modeling and perform technology vs. architecture trade-offs