

# **CLADISS-2D**

## ***a generic laser diode/TWA Model***

Dominic F.G. Gallagher

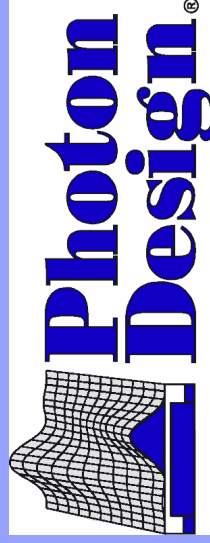


*“propagating ideas”*

**NUSOD-04**

## About Photon Design

- started in 1992
- based in Oxford, United Kingdom
- licenses in 30 countries around the World
- founded to serve the photonics community with state-of-the-art modelling tools

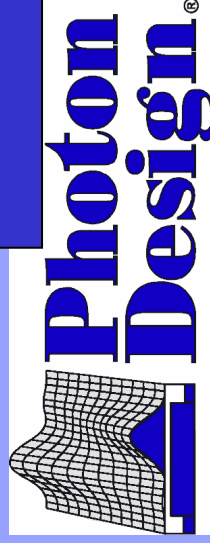


*“propagating ideas”*

**NUSOD-04**

## Optoelectronic Design Tools

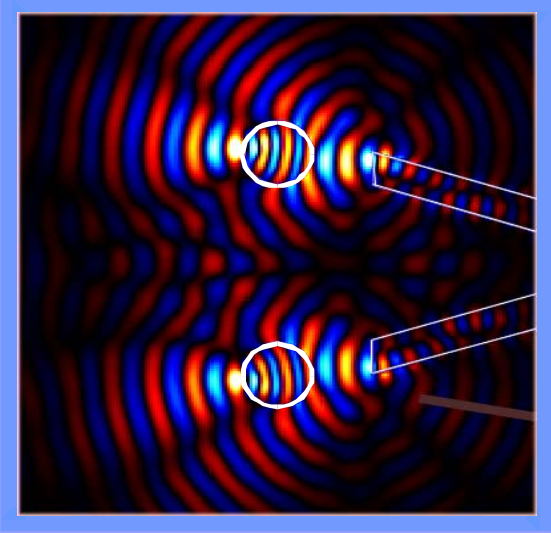
- CLADISS-2D
  - time domain, 2.5D, z,x, some y
- HAROLD
  - 1D/2D, frequency domain
- i-CLADISS
  - 1D frequency domain
- FIMMWAVE
  - Maxwell Equation. mode solver
- FIMMPROP
  - rigorous Maxwell 3D propagation tool
- OmniSim
  - omni-directional 2D/3D propagation tool



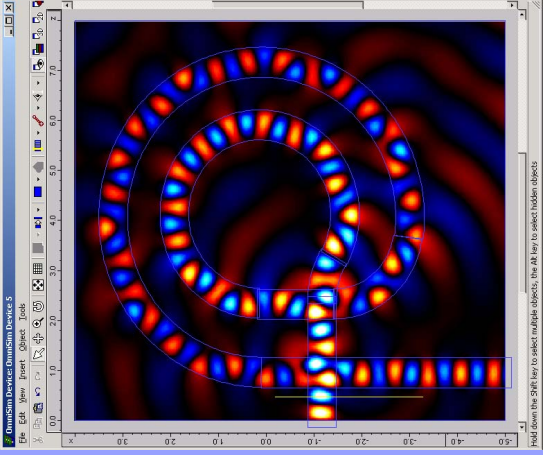
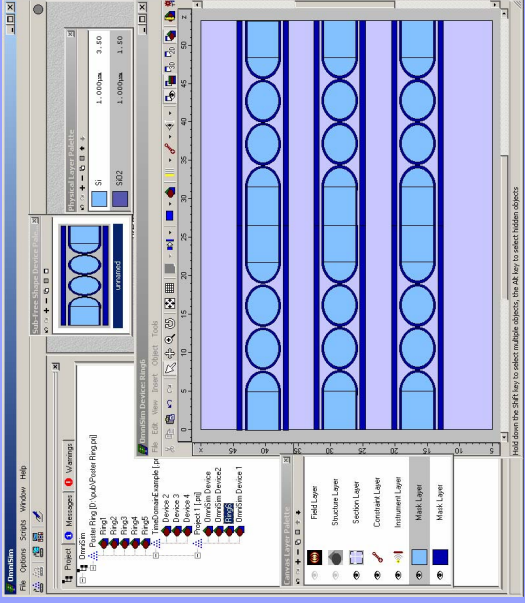
*“propagating ideas”*

OmniSim

direction-agnostic layout



2D/3D FDTD



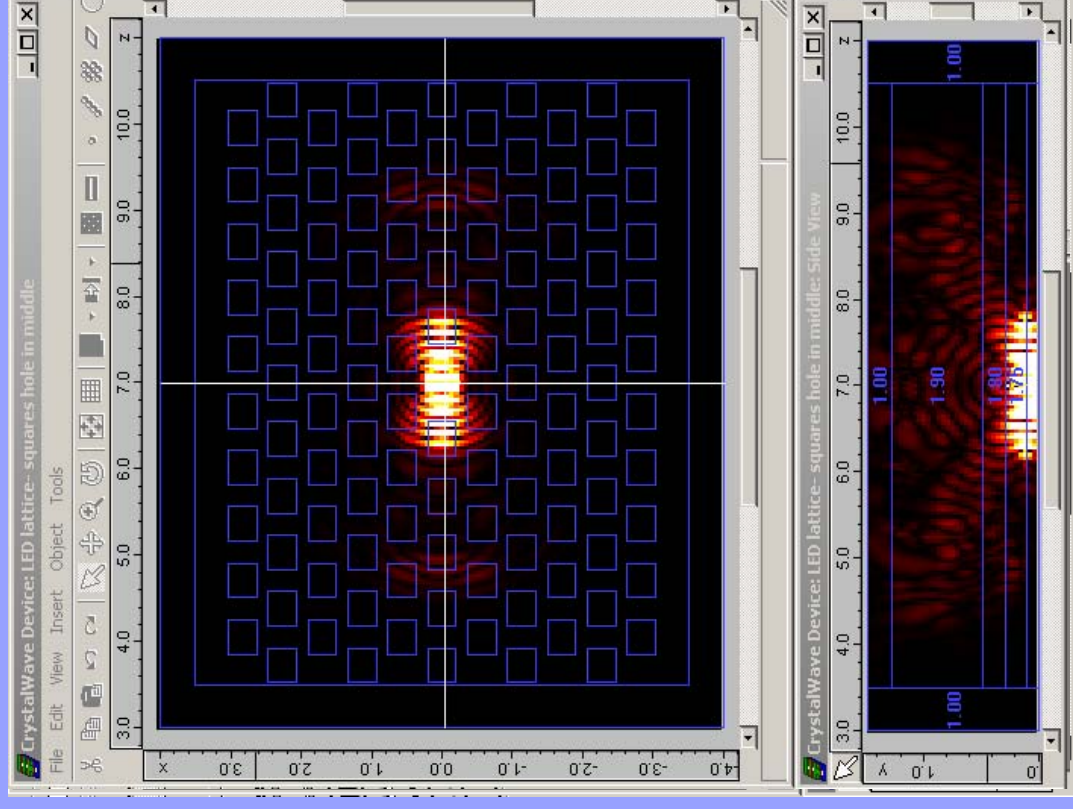
fast frequency-domain engine

*“propagating ideas”*

The logo for Photon Design, featuring a stylized wireframe graphic of a curved surface above the company name in a bold, blue, serif font.

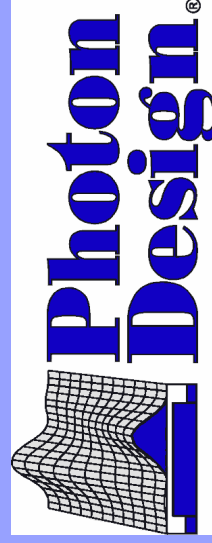
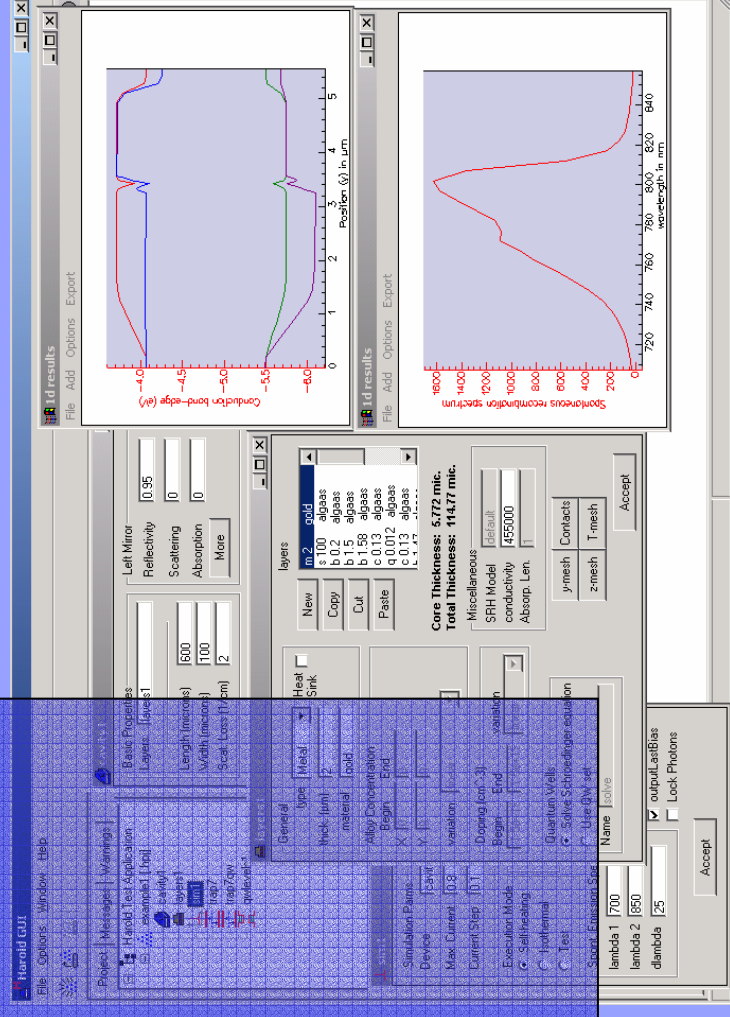
# NUSOD-04

## Design of LED



## HAROLD

- in cooperation with University of Madrid
- frequency domain
- steady-state, x-only and xz
- self-consistent electron model:
  - Poisson Equation
  - drift-diffusion
  - capture/escape
- Recombination processes:
  - stimulated and spontaneous
  - Shockley-Read-Hall
  - Auger
- self-consistent thermal models

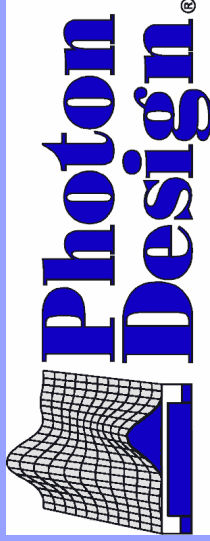


*“propagating ideas”*

**NUSOD-04**

## i-CLADISS

- Engine developed at University of Gent
- frequency domain basis
- 1 dimensional (z-only)
- multi-longitudinal mode
- powerful fast small-signal models for:
  - linewidth
  - AM, FM,
  - noise
- DC Module for LI characteristics
- AC & Noise Modules (small signal)
- Time Domain module

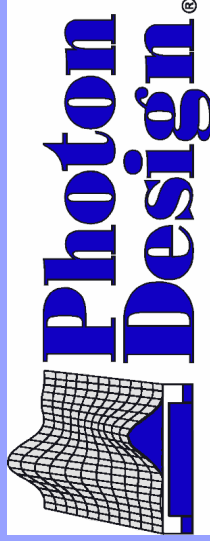


*“propagating ideas”*

## CLADISS-2D

## 3D?

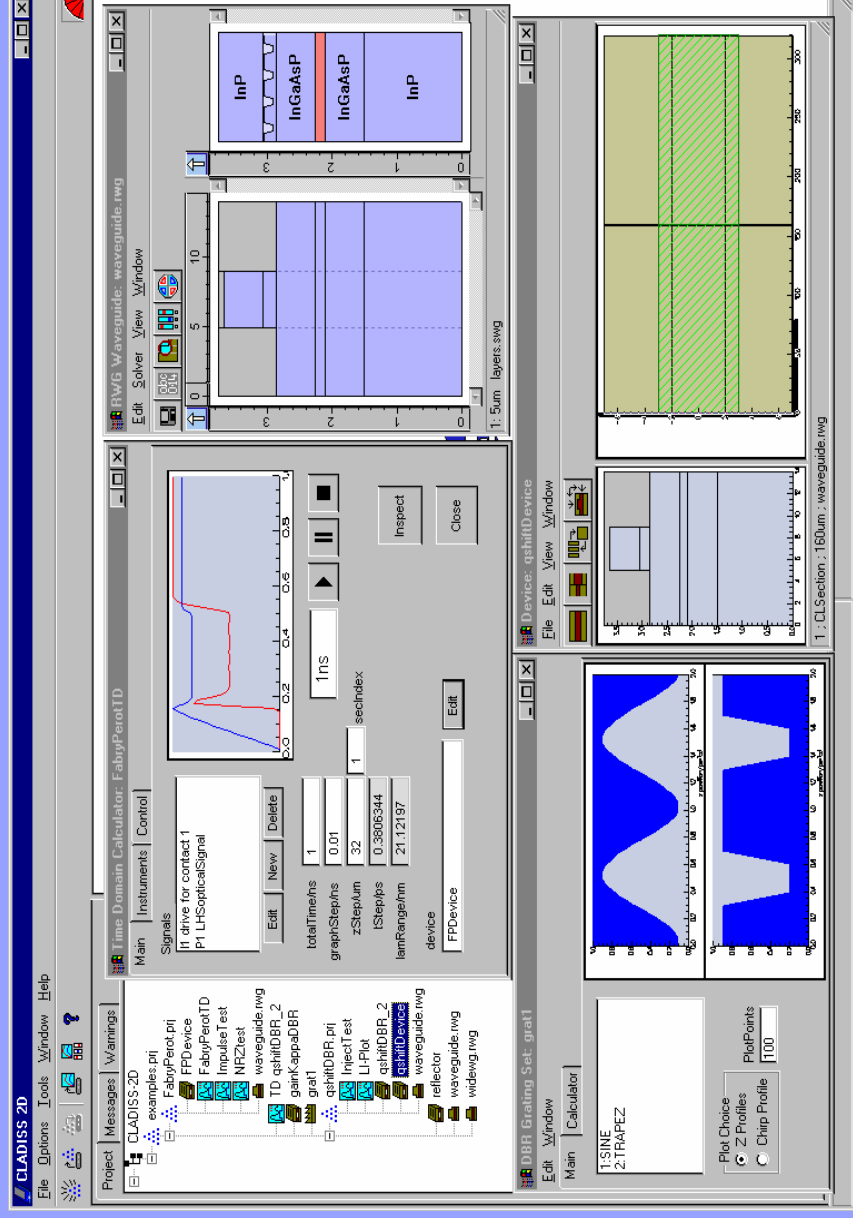
- comprehensive laser diode model
- travelling wave amplifiers (TWA/SOA)
- multi-section 3D device structures, including
  - DFB's, DBRs,
  - tunable lasers...
  - mode locking
  - external cavity
- integrated waveguide models
- integrated grating calculator



*“propagating ideas”*

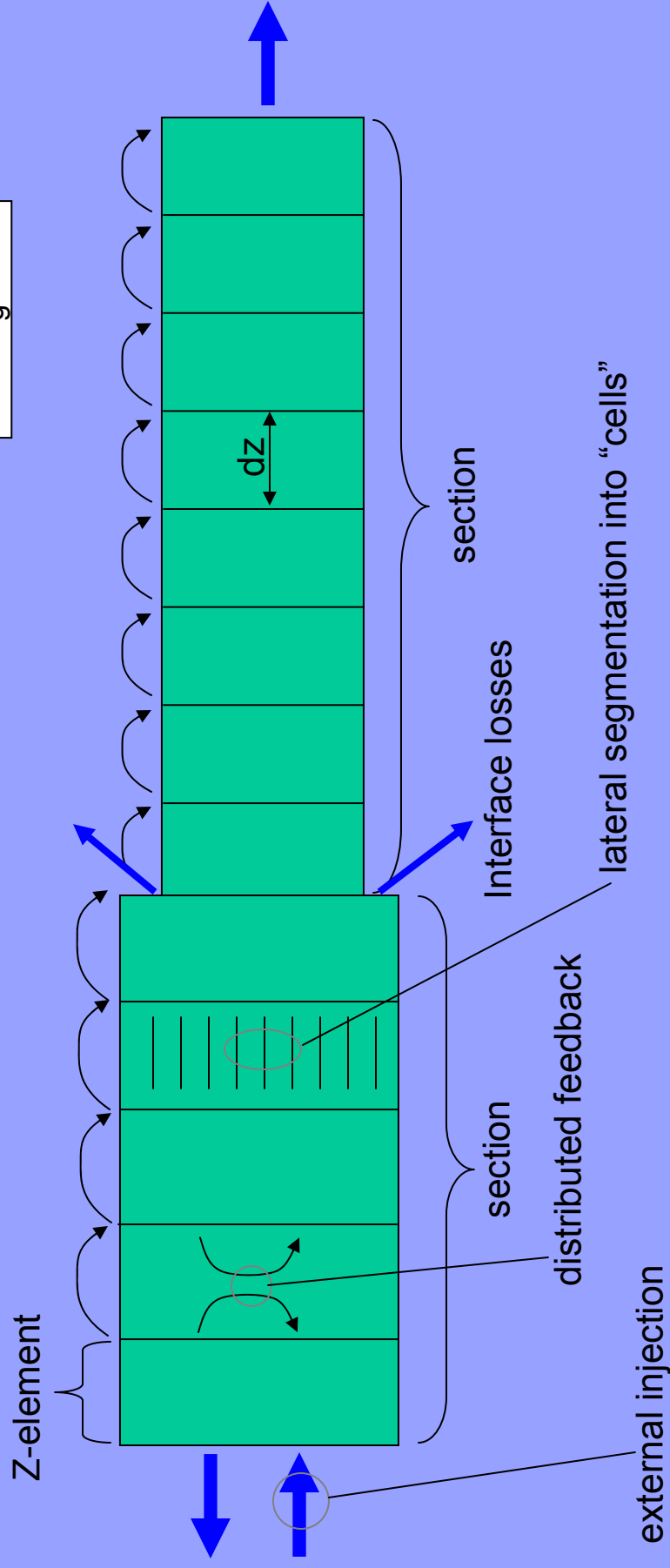
**NUSOD-04**

## Full Professional GUI Interface

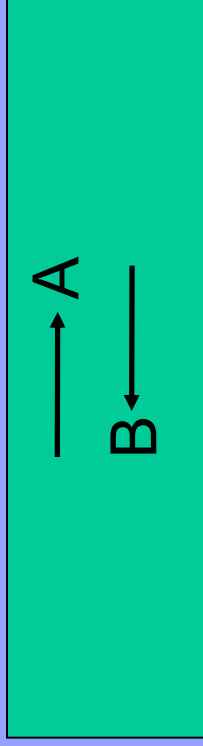


## Segmentation of a Device

$$dz = v_g \cdot dt$$

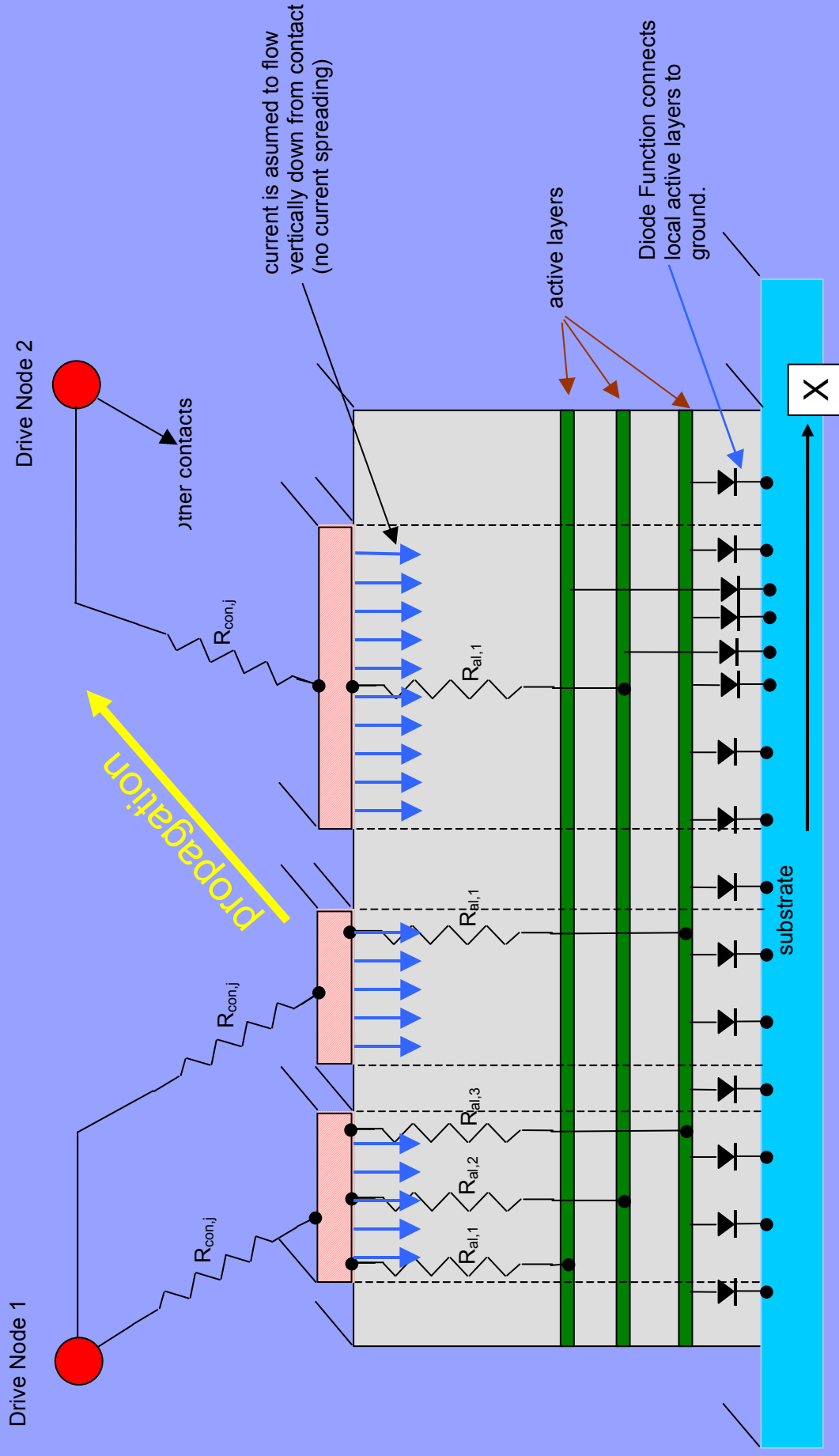


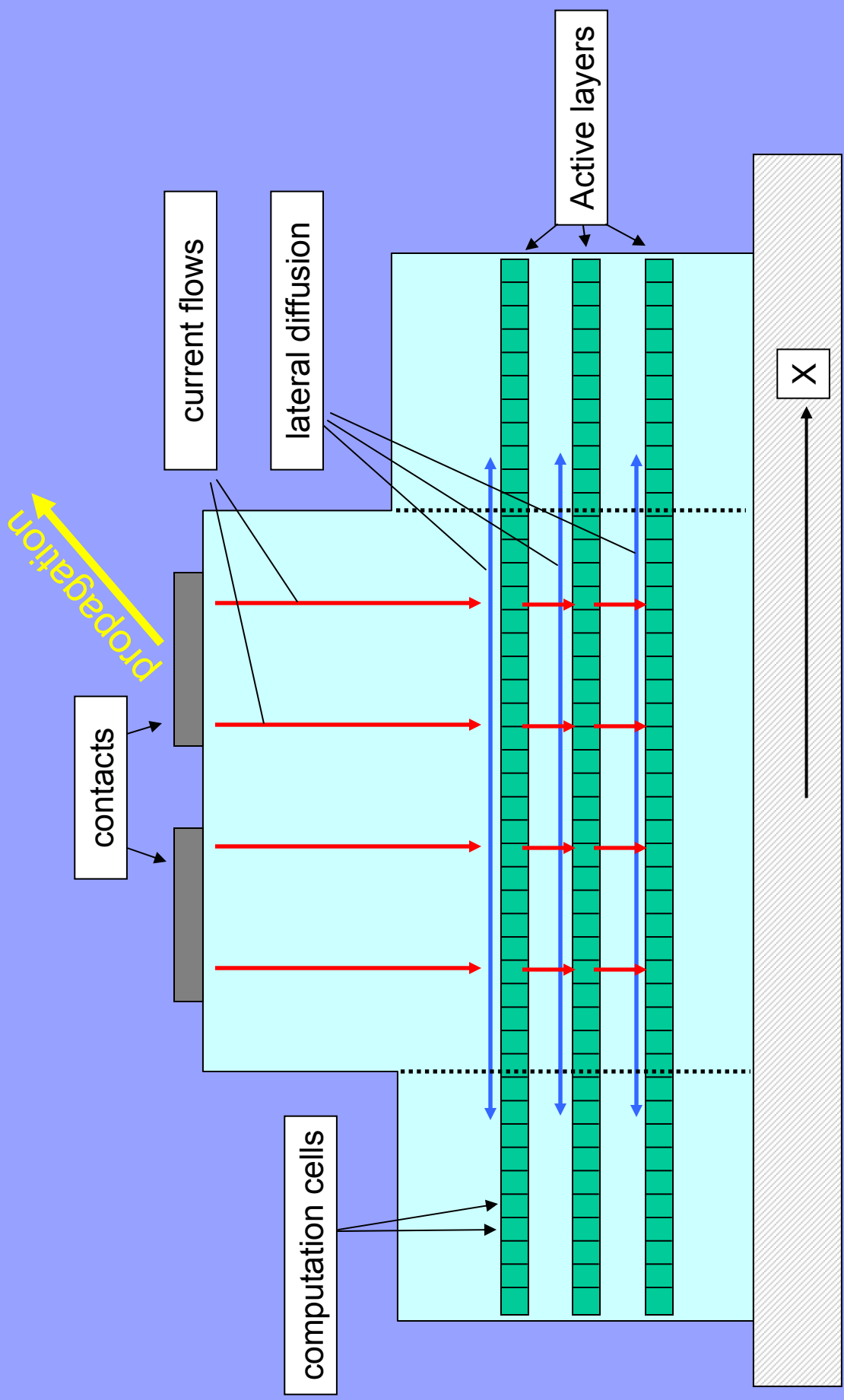
## Advection Equations



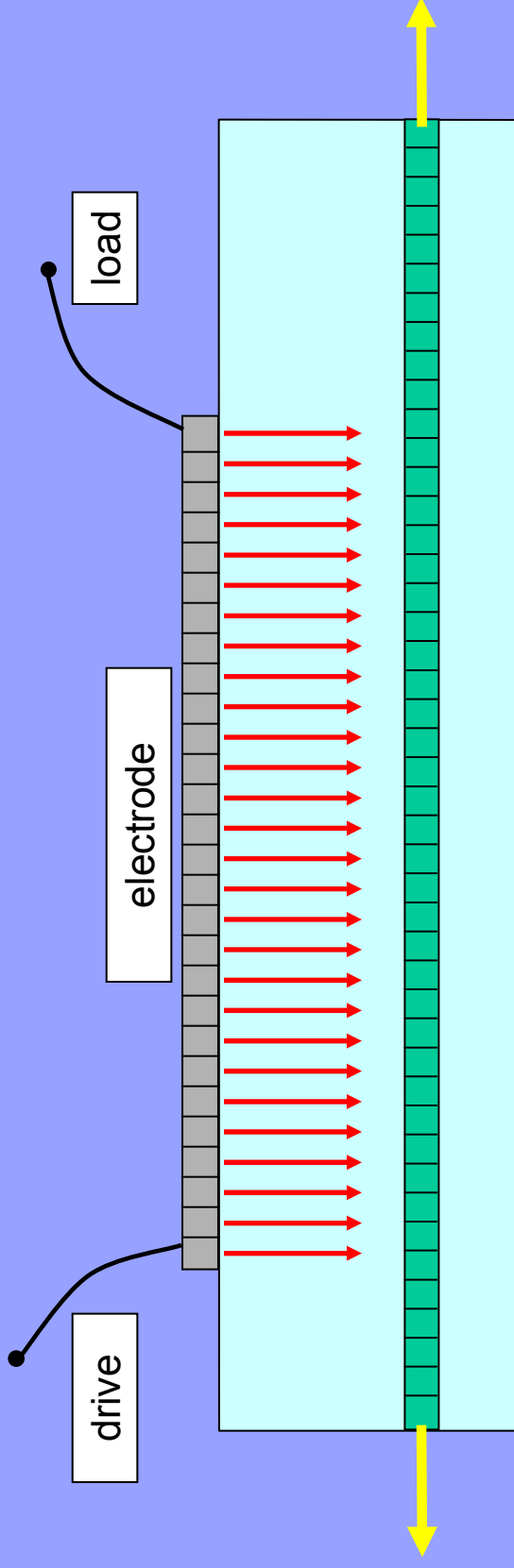
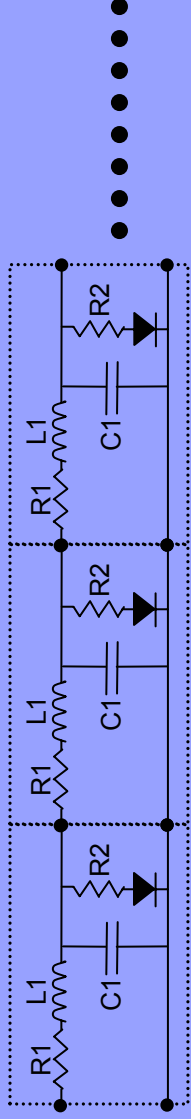
$$\frac{1}{v_g} \frac{\partial A}{\partial t} + \frac{\partial A}{\partial z} = j \cdot \kappa \cdot B + (g - j \cdot \delta) A$$

$$\frac{1}{v_g} \frac{\partial B}{\partial t} - \frac{\partial B}{\partial z} = j \cdot \kappa \cdot A + (g - j \cdot \delta) B$$

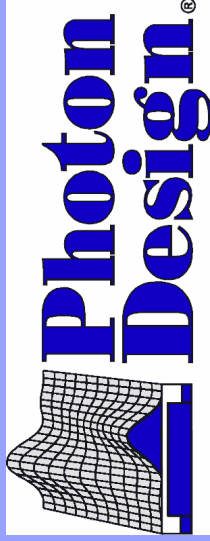
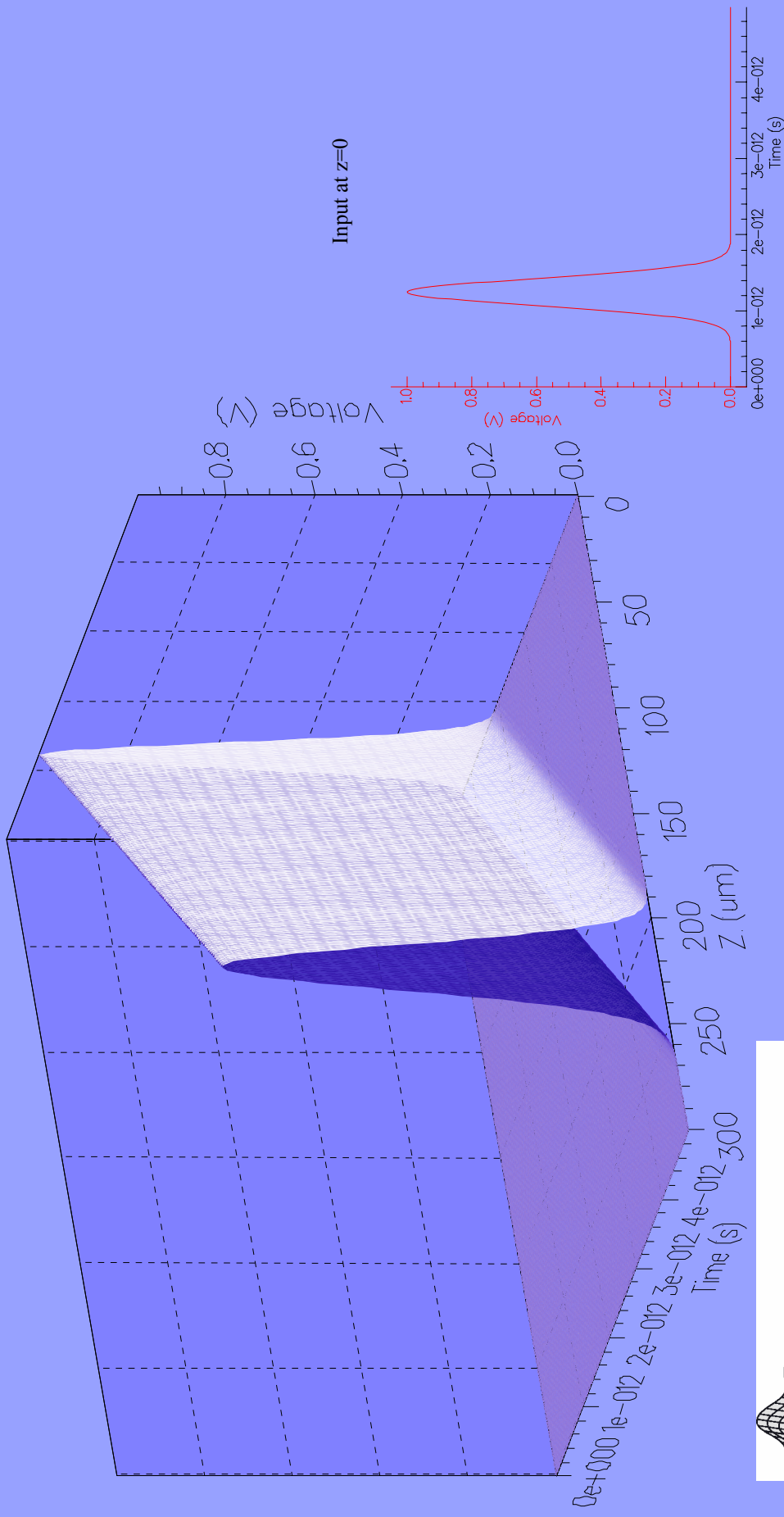




## Travelling Wave Electrode Model



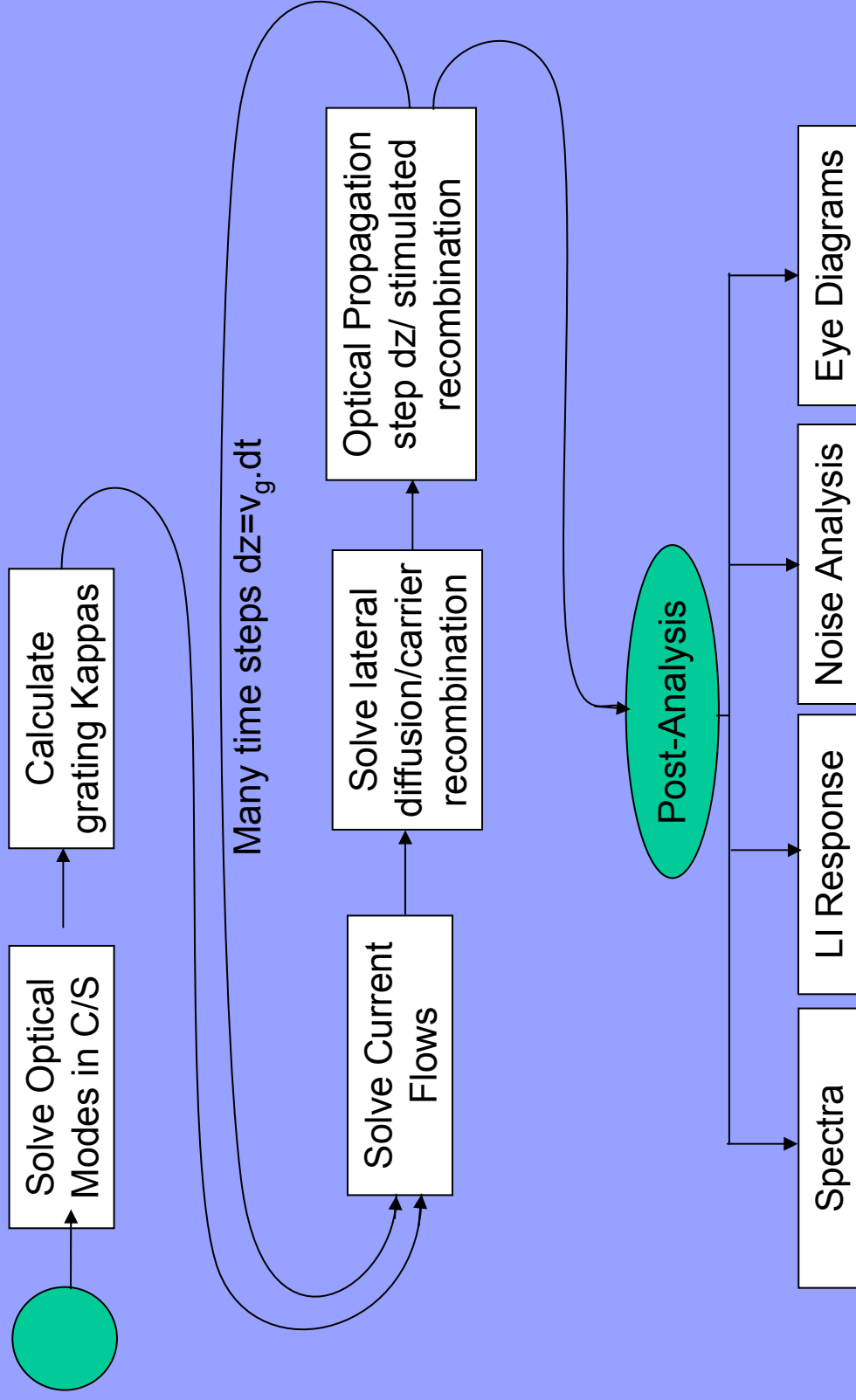
## A Gause pulse propagating along a travelling wave electrode



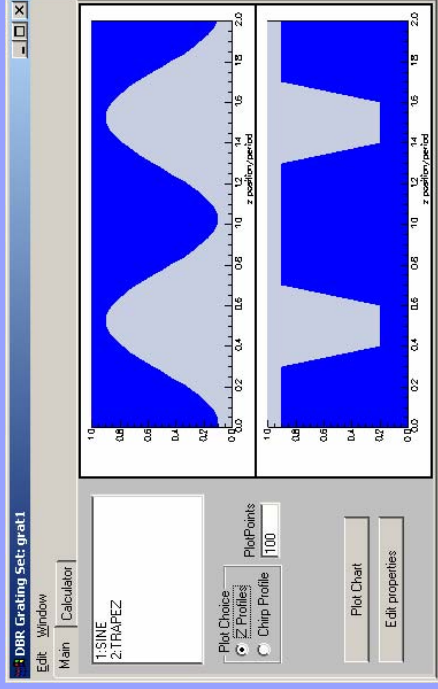
*“propagating ideas”*  
Propagating along z

**NUSOD-04**

## Algorithm Flowchart

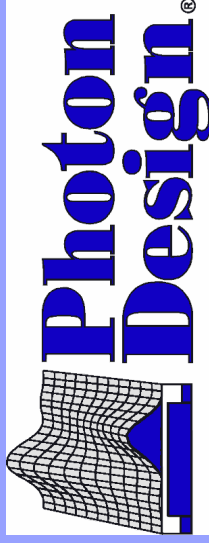


## Grating Features



user defined mechanical shape

- define physical grating or enter kappa directly
- Index gratings
- loss gratings
- gain gratings
- any combination of above
- chirped gratings



*“propagating ideas”*

NUSOD-04

## Material Description

A material definition contains a specification for the following parameters and functions: (x is a material parameter, e.g. Al content in GaAlAs, T is temperature)

- refractive index function,  $\mu_e(\lambda, T, x, \text{Ne})$
- material absorption,  $\alpha(\lambda, T, x)$
- electrical conductivity,  $\rho_e$  (for future current spreading extensions)
- thermal conductivity,  $\rho_h$  (for future thermal heating modelling)

In addition, if the material is *active* then the following parameters and functions may also be defined

- gain function  $g(\lambda, \text{Ne}, T, P)$
- gain non-linearity:

$$g(\lambda, \text{Ne}, T, P) = g_1(\lambda, \text{Ne}, T) / (1 + g_2 \cdot P): g_2(\lambda, \text{Ne}, T)$$

- intervalence band absorption: a 12 term equation. providing wavelength, carrier and temperature dependence:

$$\alpha_{\text{int}}(\lambda, \text{Ne}, T)$$

- carrier diffusion coefficient:

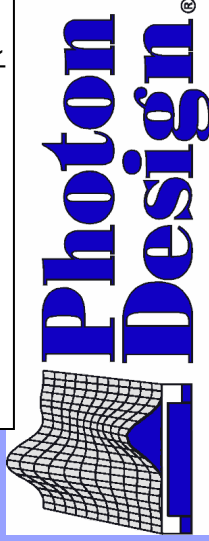
$$D(\text{Ne}) = D_0 + D_1 \cdot \text{Ne}$$

- non-radiative spontaneous carrier lifetime:

$$\tau_{\text{nr}}(\text{Ne}) = b_0 + b_1 \cdot \text{Ne} + b_2 \cdot \text{Ne}^2$$

- radiative spontaneous carrier lifetime (spontaneous emission):

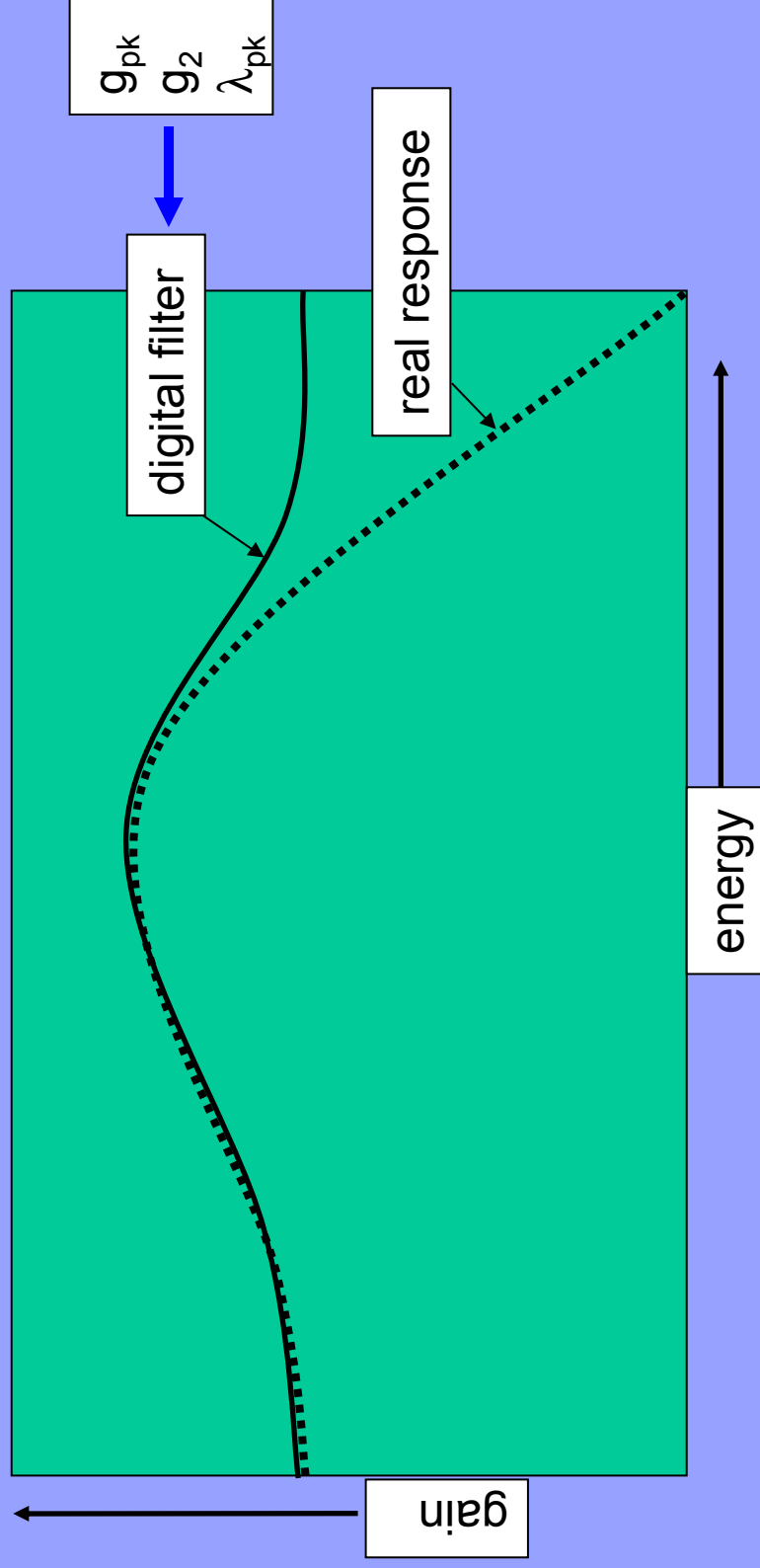
$$\tau_{\text{r}}(\text{Ne}) = c_0 + c_1 \cdot \text{Ne} + c_2 \cdot \text{Ne}^2$$



*“propagating ideas”*

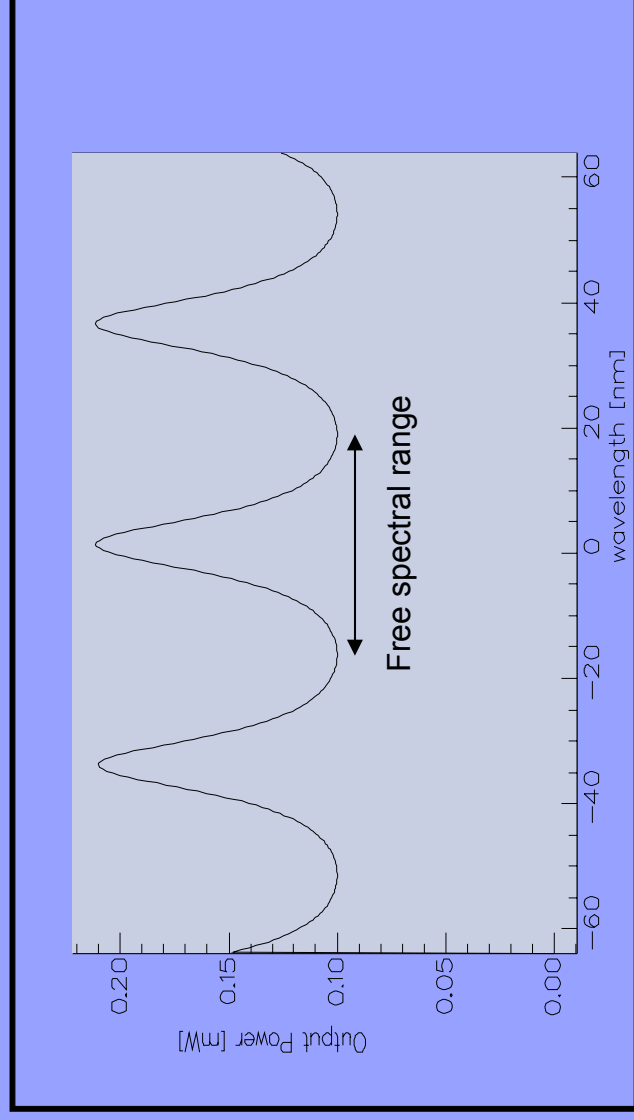
NUSOD-04

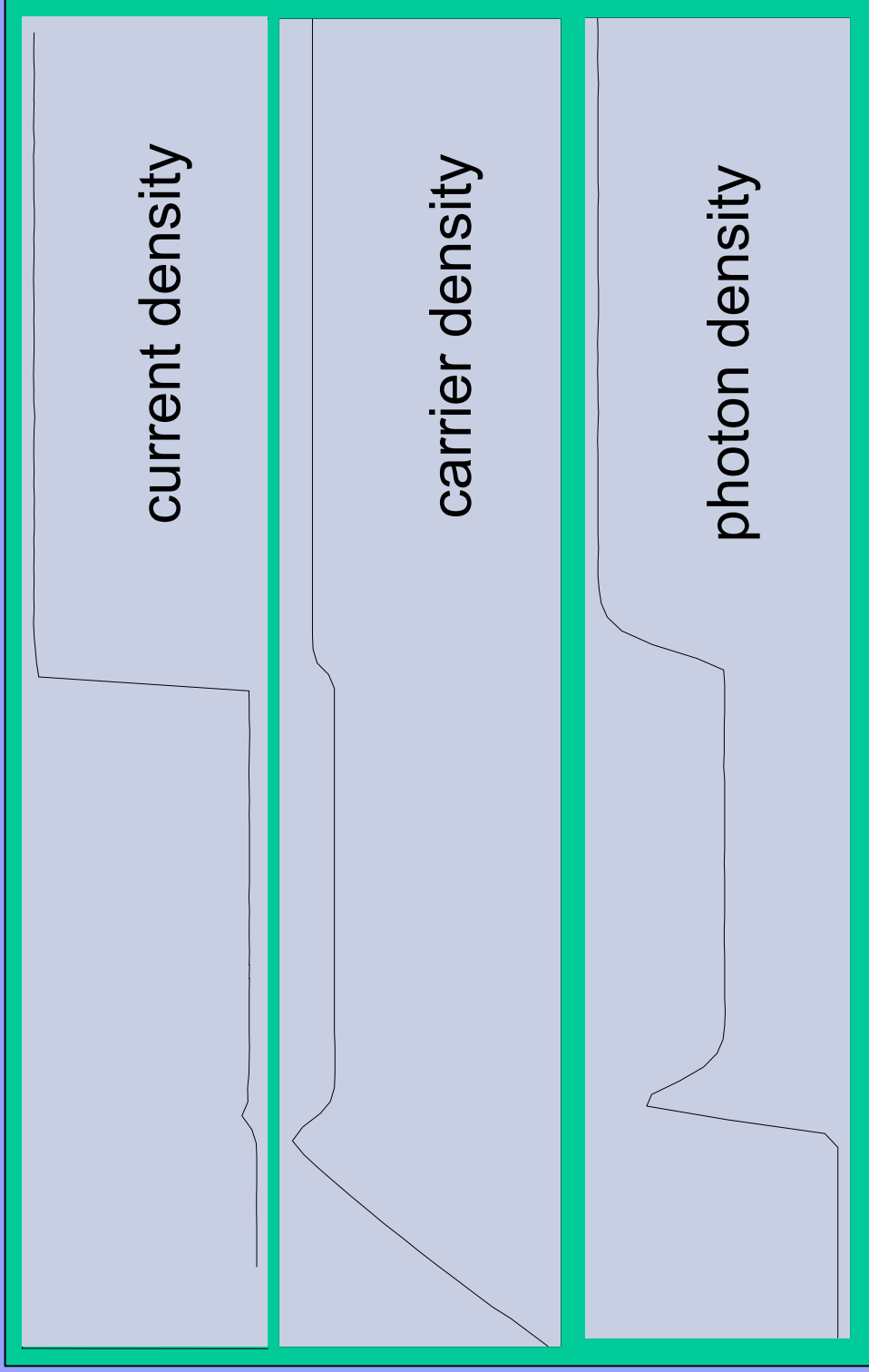
## Gain Function



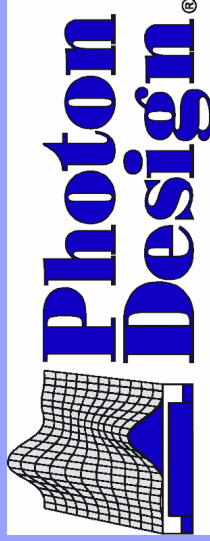
- digital filter is periodic
- can match gain peak, curvature and position
- must dynamically change filter above bandgap - awkward

Gain Function





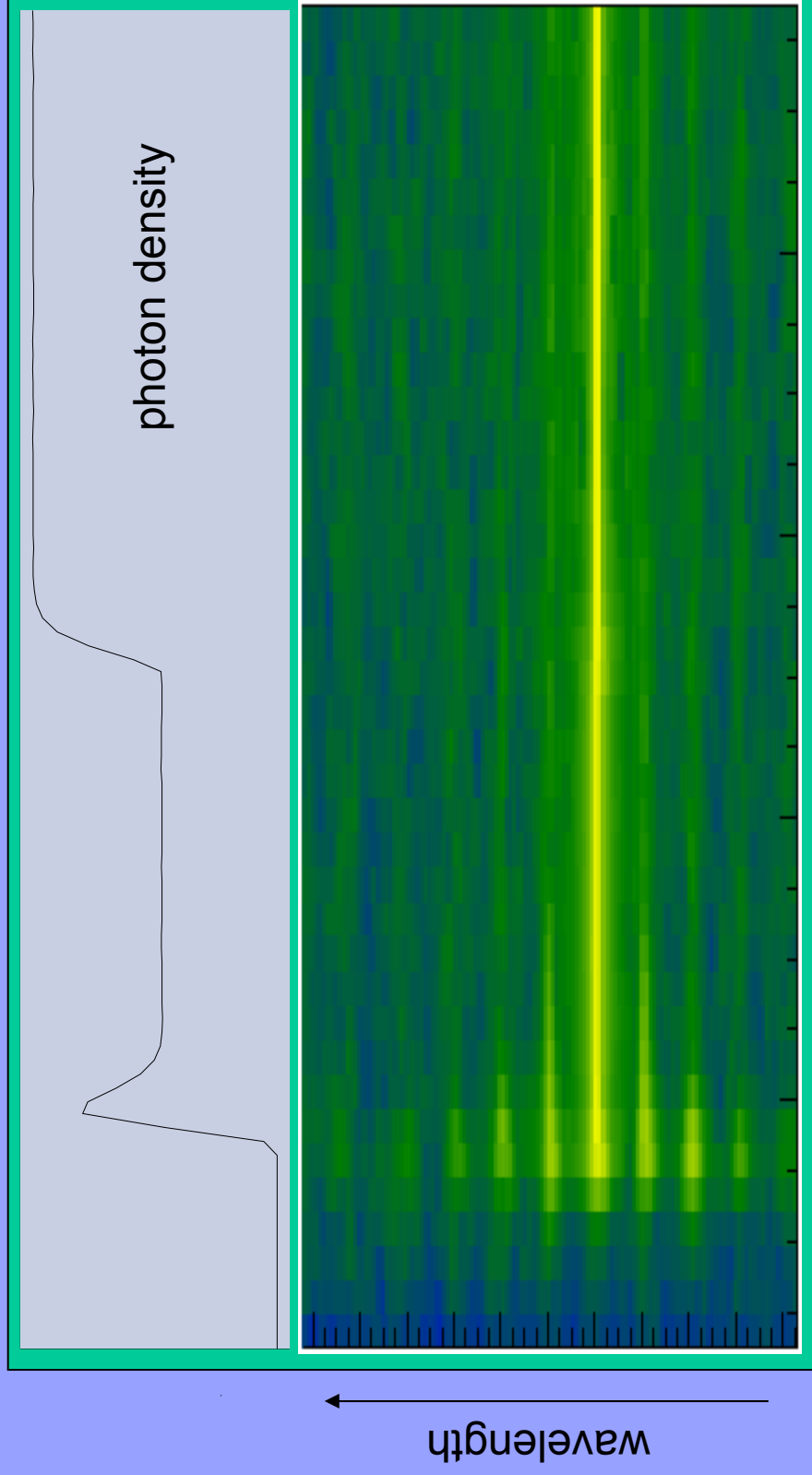
time: 1ns



*“propagating ideas”*

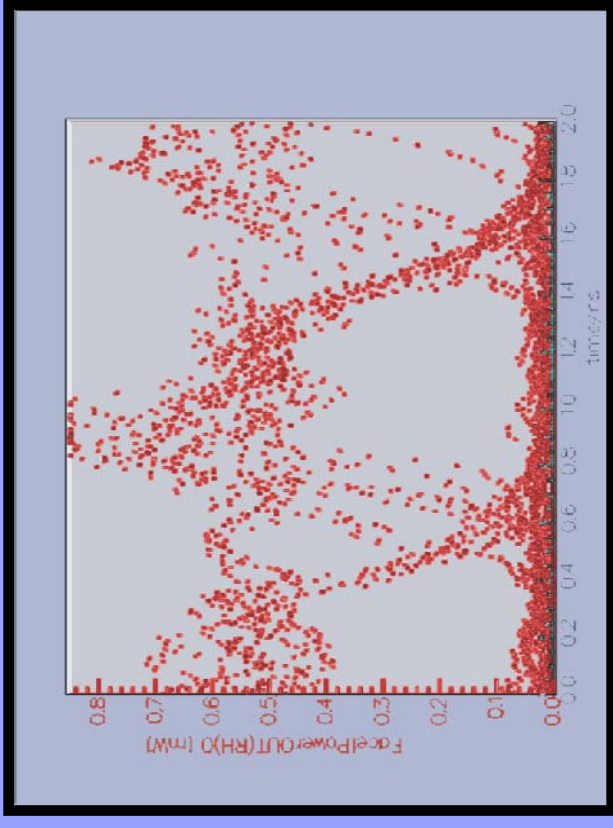
**NUSOD-04**

## Time resolved spectra of a FP laser



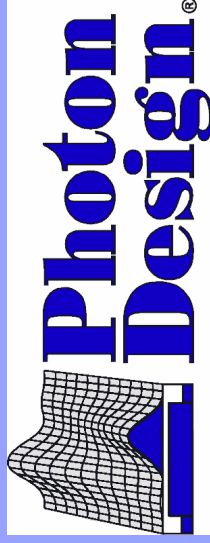
## Analysis

- Optical Spectra at time T or time resolved
- RIN and other Intensity spectra
- threshold measurement
- eye diagrams



## State Inspection

- Carrier density, temperature distribution of cross-section
- Carrier density along z
- Optical intensity of each mode along z



*“propagating ideas”*

**NUSOD-04**

## Small Signal Analysis

$$N = N_1 + \delta N$$

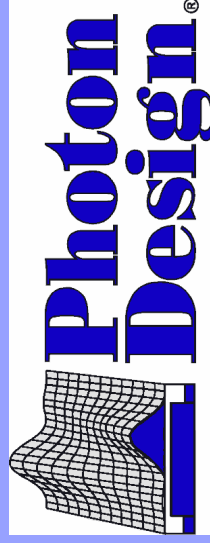
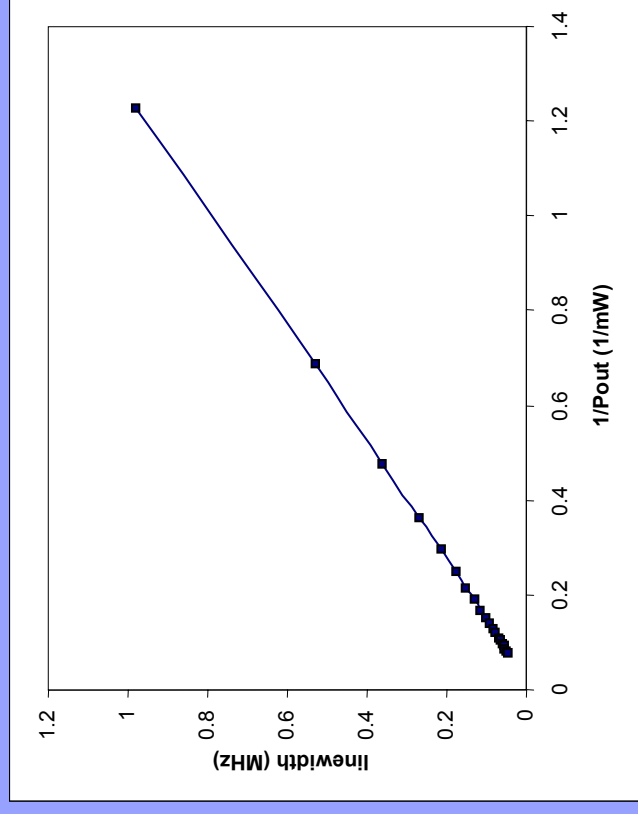
$$\psi_f = \psi_{f1} + \delta\psi_f$$

$$\psi_b = \psi_{b1} + \delta\psi_b$$

- Solve  $\{N_1, \psi_{f1}, \psi_{b1}\}$  using time-domain run until steady state.
- Solve  $(\delta N, \delta\psi_f, \delta\psi_b)$  - small signal equations

### Features:

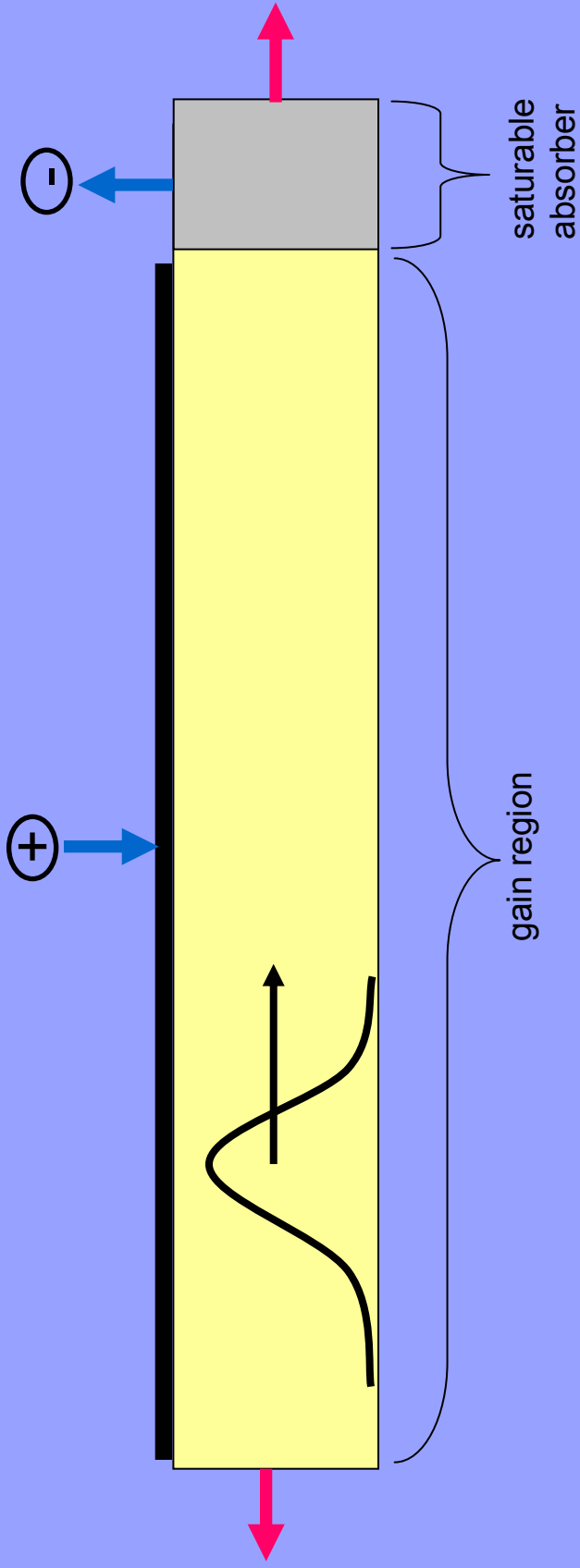
- Linewidth
- AM
- FM
- No quantum noise!



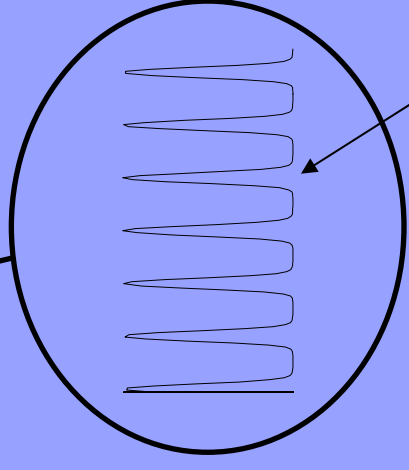
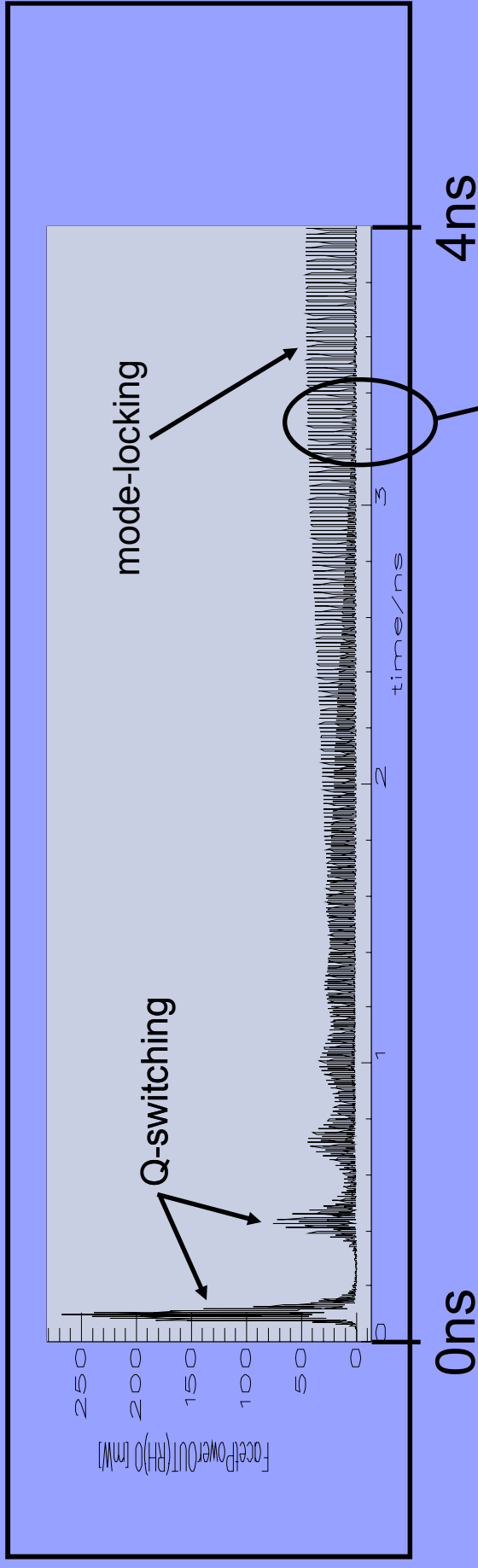
*“propagating ideas”*

NUSOD-04

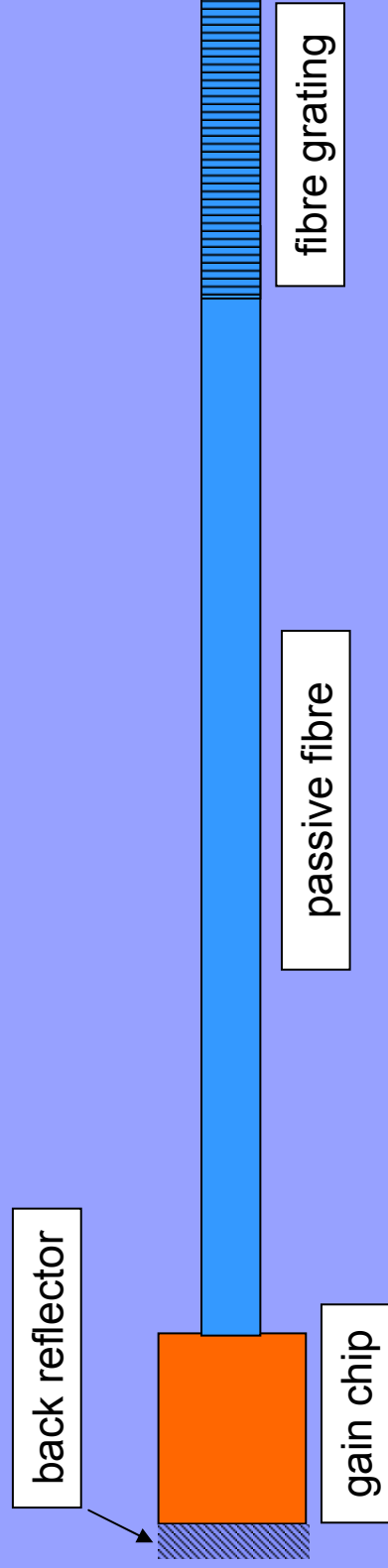
## Mode-Locking



## Mode-Locking



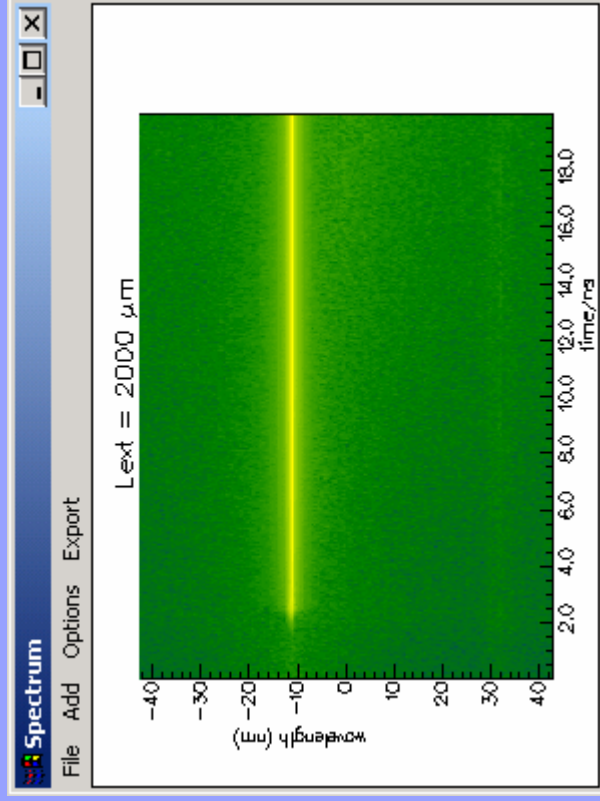
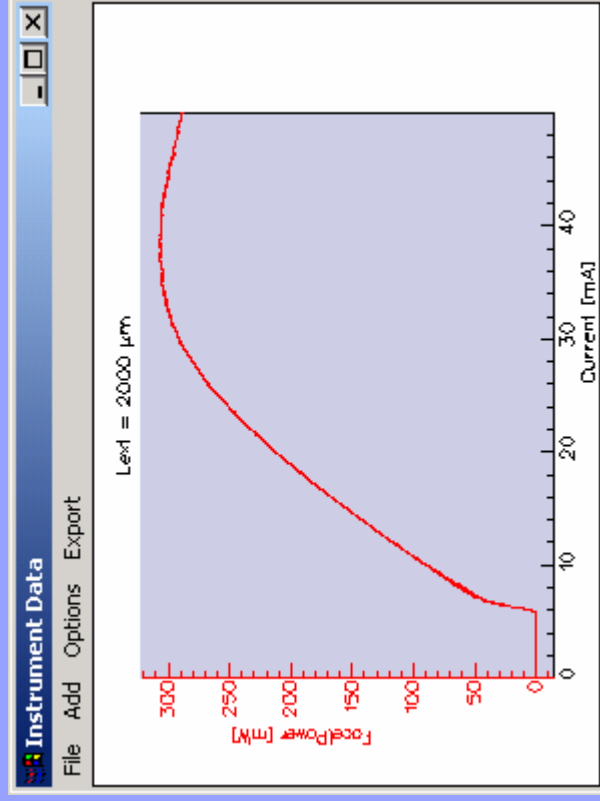
## External Cavity Laser



Lext = 2000  $\mu\text{m}$

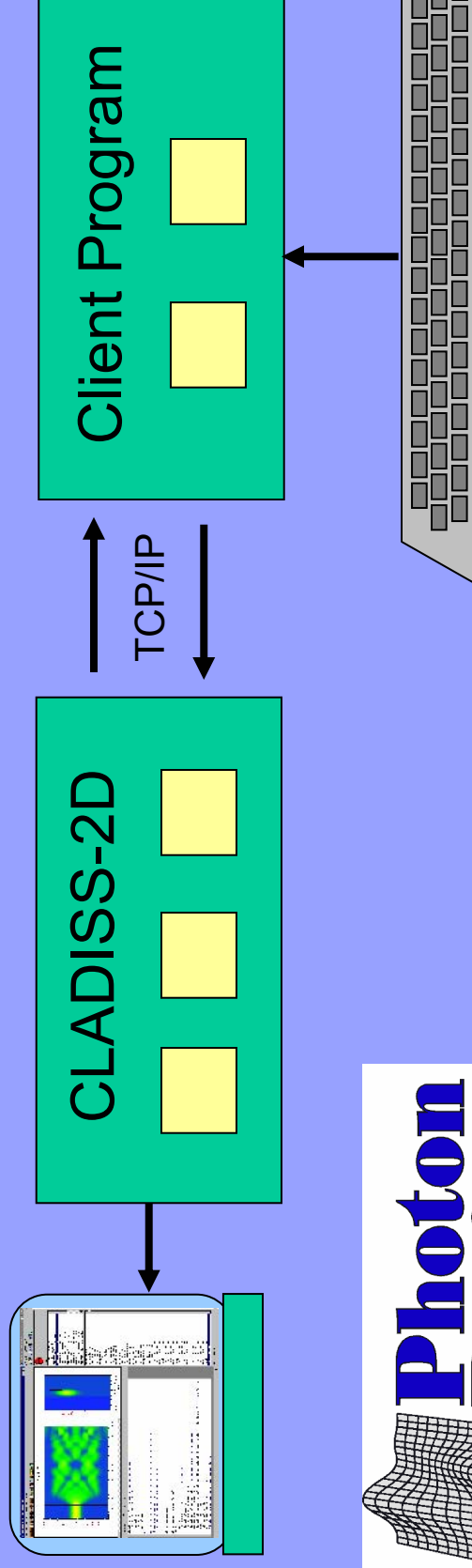
*“propagating ideas”*

**NUSOD-04**

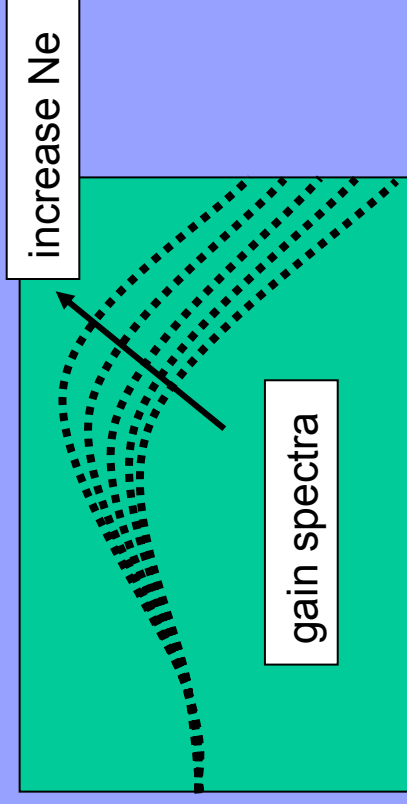


## Client-Server Framework

- Most of CLADISS-2D can be controlled either from:
- the command line interface, or
- from your own programs via a TCP/IP.
- Integrate our tools with your own code or in-house expertise
- extend with powerful optimisation techniques
- also macro-recorder for rapid script creation.



## Harold/CLADISS-2D Interaction



Harold

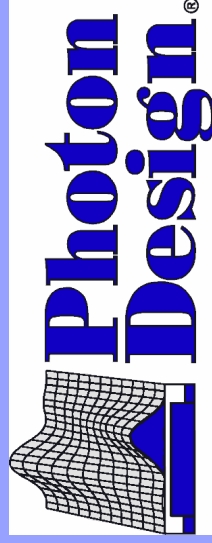
solve  
heterostructure  
problem

Curve Fitting

CLADISS-2D

$g_{pk}(N)$   
 $g_2(N)$   
 $\lambda_{pk}(N)$   
 $\tau_{spon}$   
...

- solve heterostructure just a few times at start of simulation.
- maintain speed of CL2D
- out-of-bound detectors ensure simulation stays within fit range.



*“propagating ideas”*

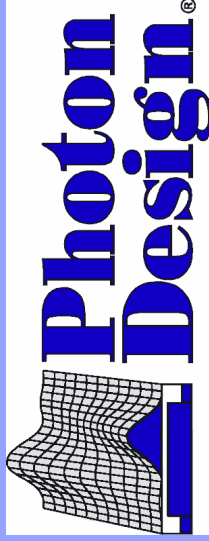
NUSOD-04

### Advantages

- noisy - stochastic device analysis
- inherently stable algorithm
- sub-threshold easy
- complex geometries easy

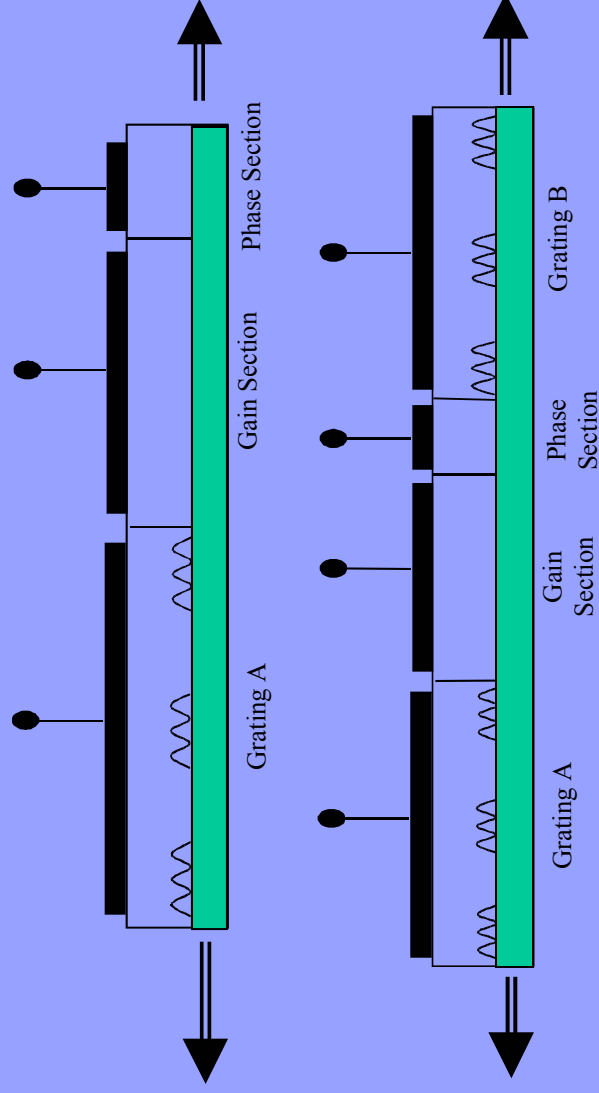
### Disadvantages

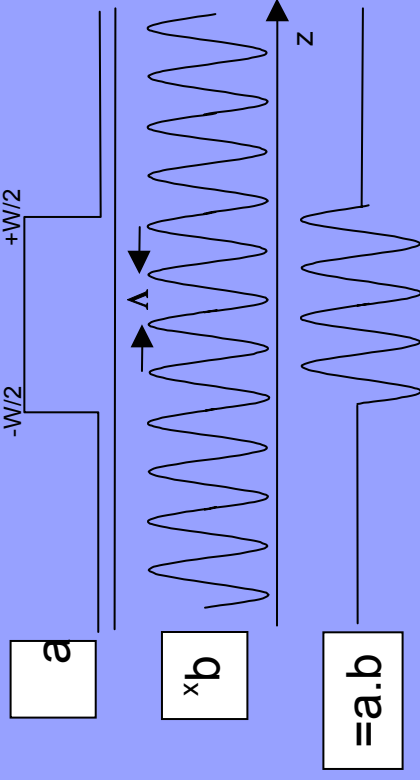
- noisy - obscures trends
- group-index rule
- must do DC characteristics in the time-domain
- limitations on form of digital filters



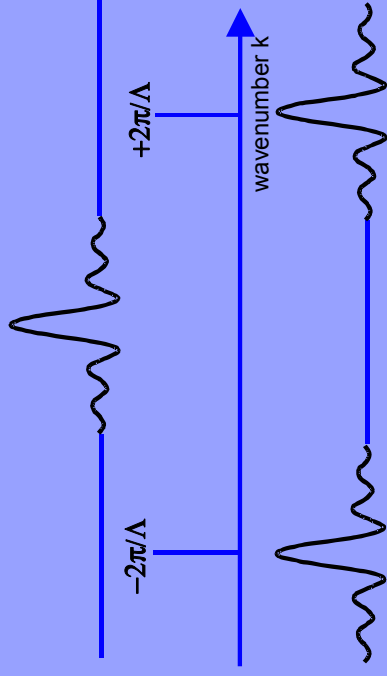
*“propagating ideas”*

## Modelling of a Sampled Grating DFB Laser

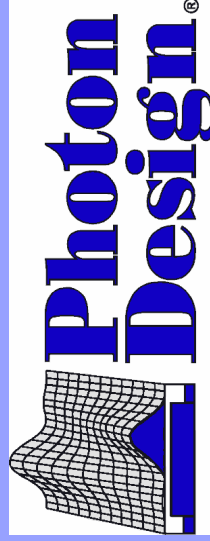




short section of grating decomposed  
into its fundamental spatial frequency  
and a "hat function".

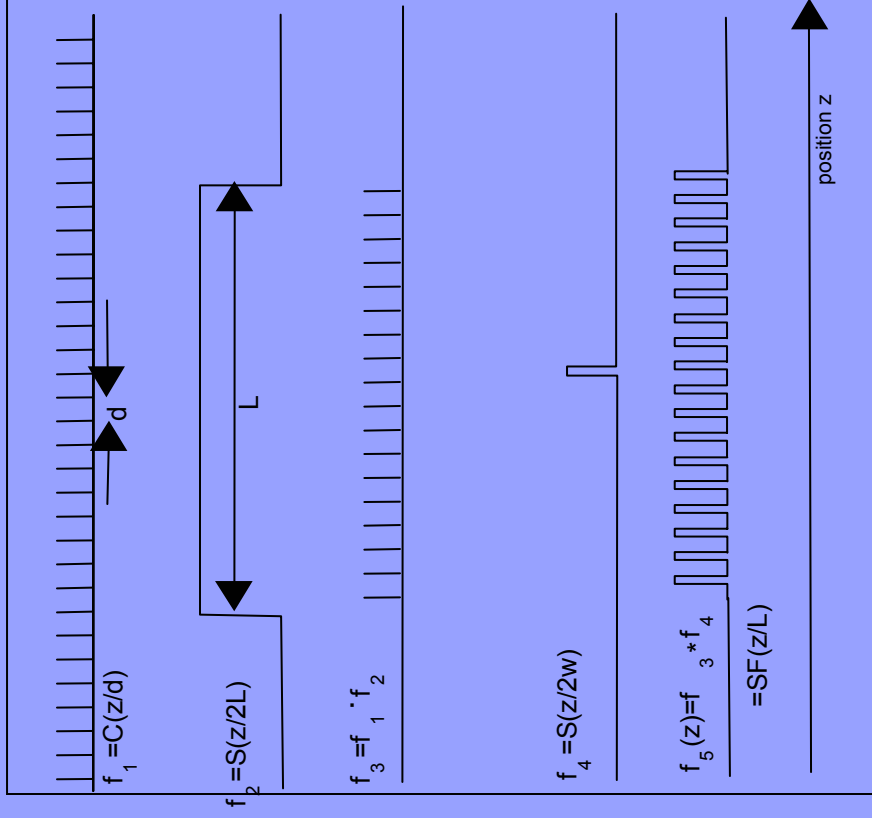


the Fourier spectra of the spatial functions.

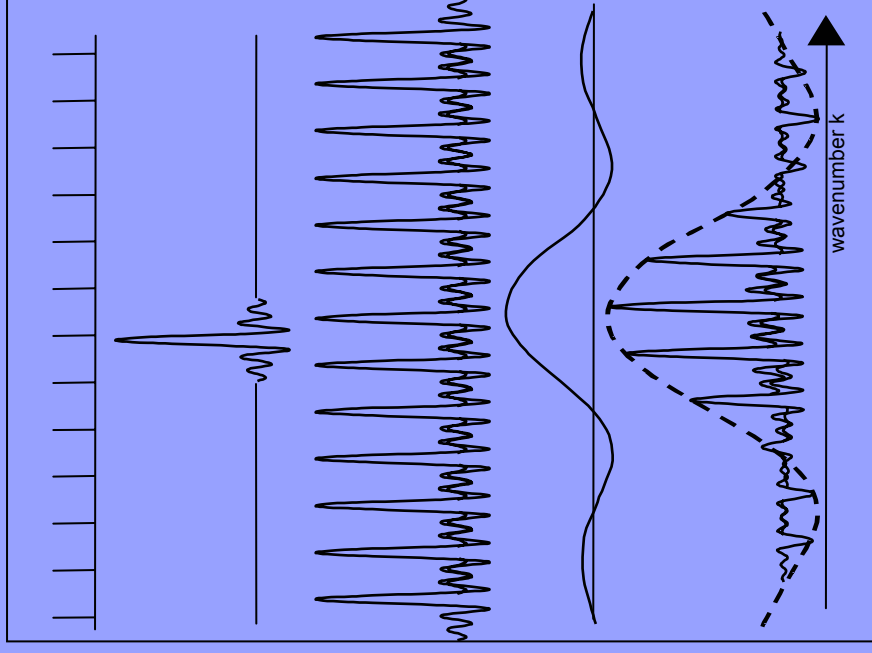


*"propagating ideas"*

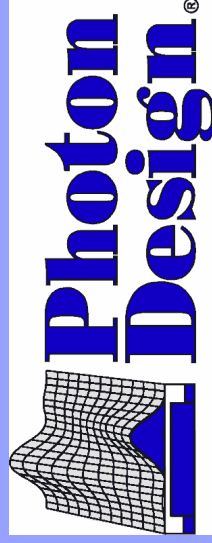
**NUSOD-04**



decomposition of a finite number of “samples”

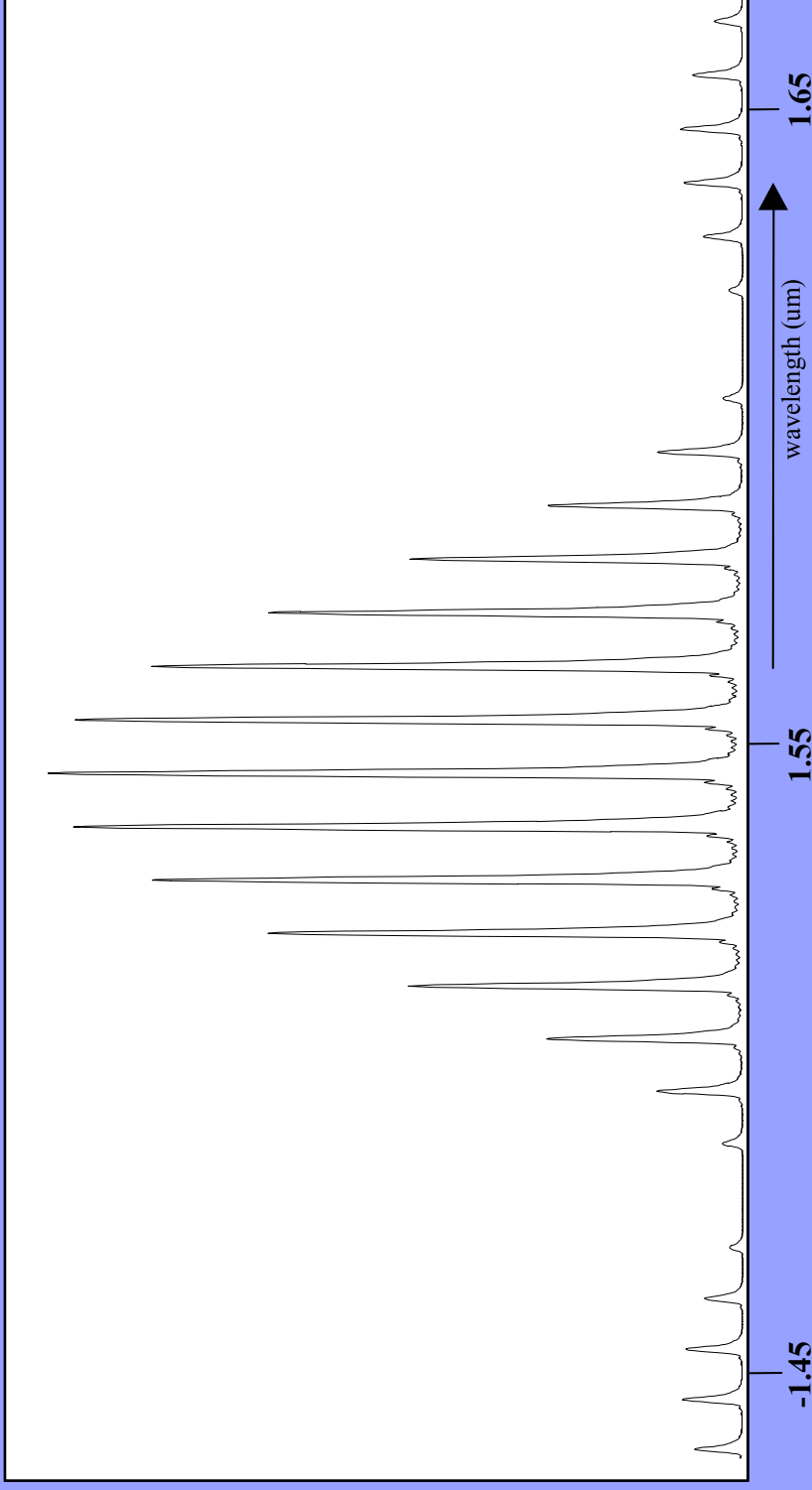


Associated spectral response

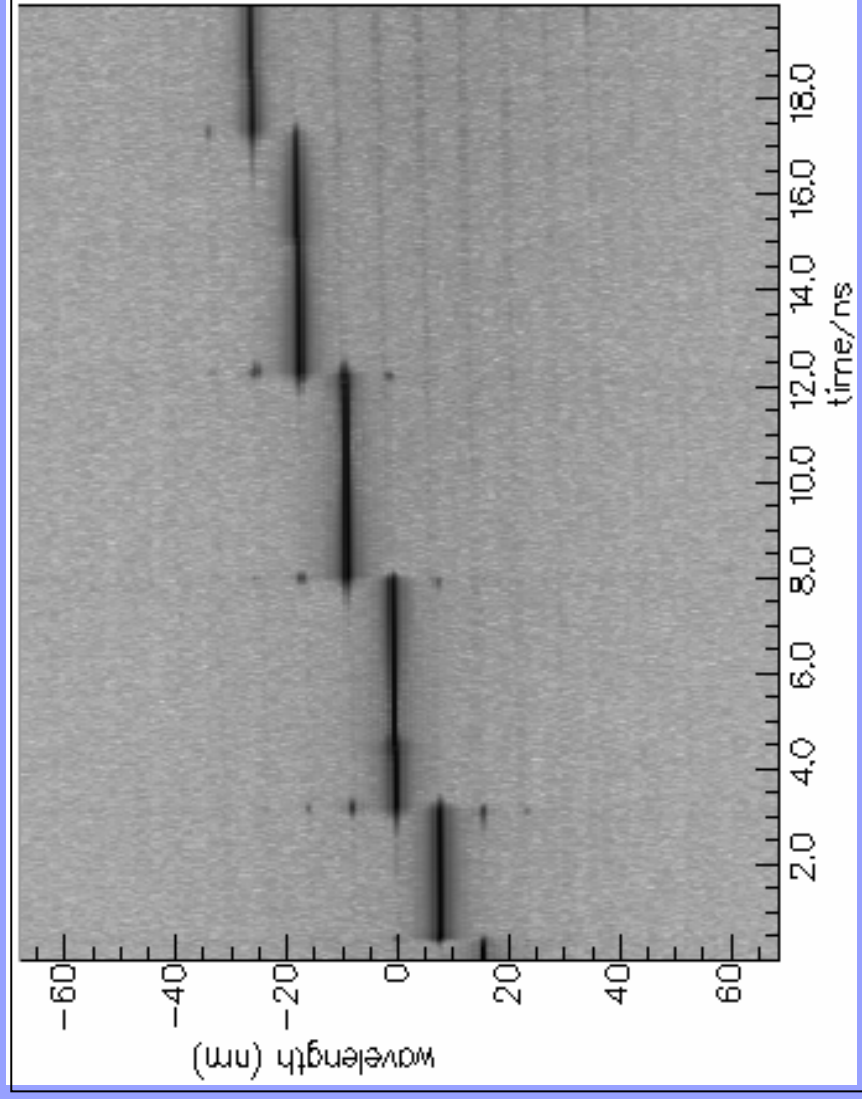


“propagating ideas”

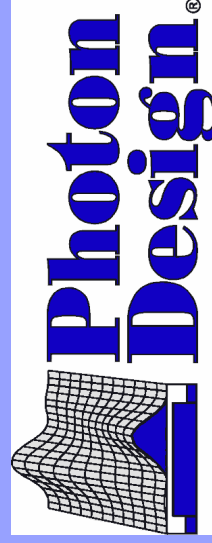
NUSOD-04



Reflection spectrum (optical power) from a sampled-grating. 5um grating samples separated by 35um with an overall length of 320um.



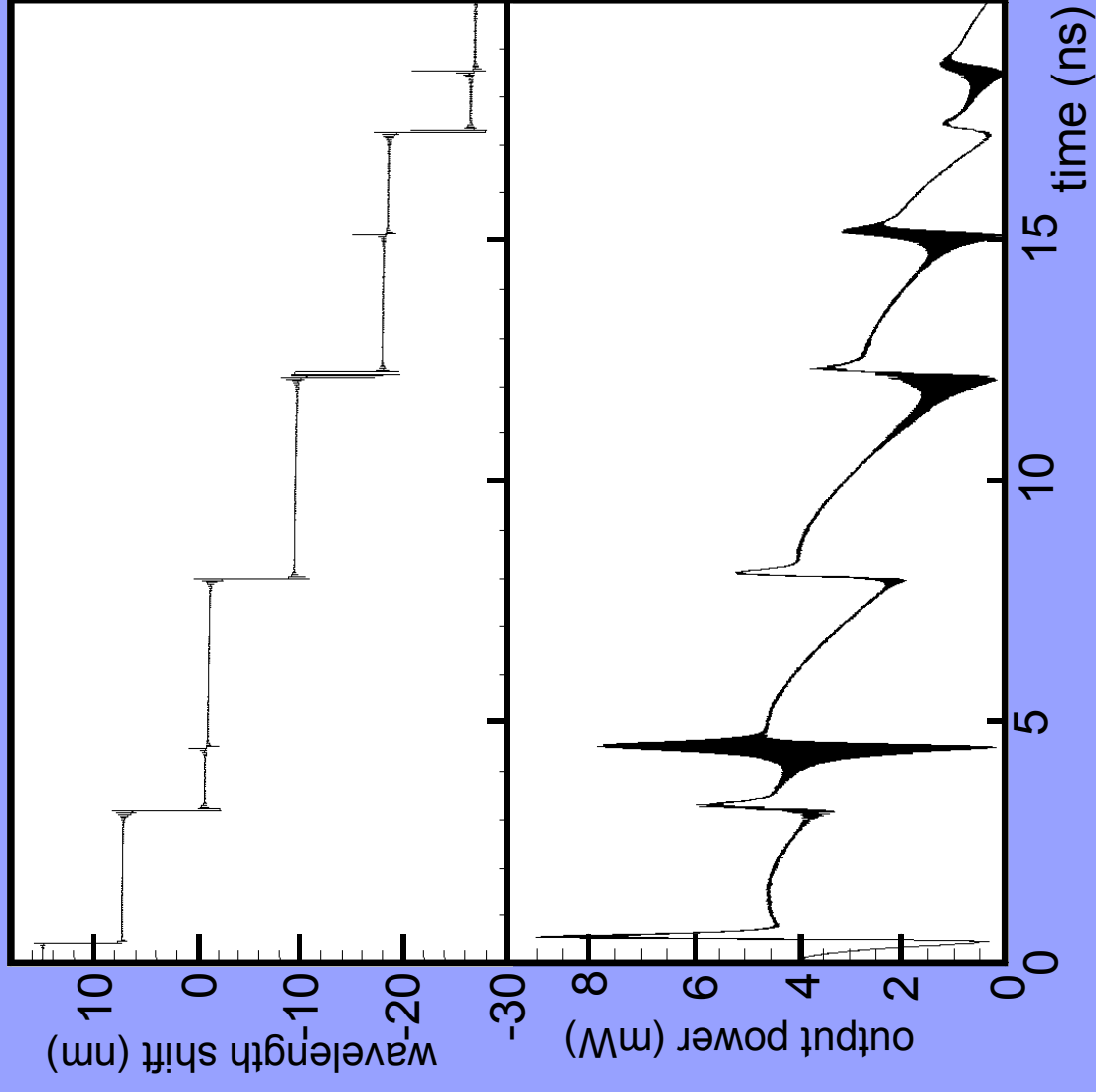
time evolving spectrum of SG-DFB as  
current to Grating A is varied.



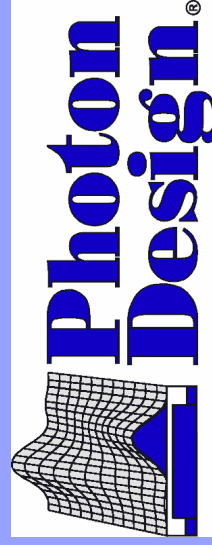
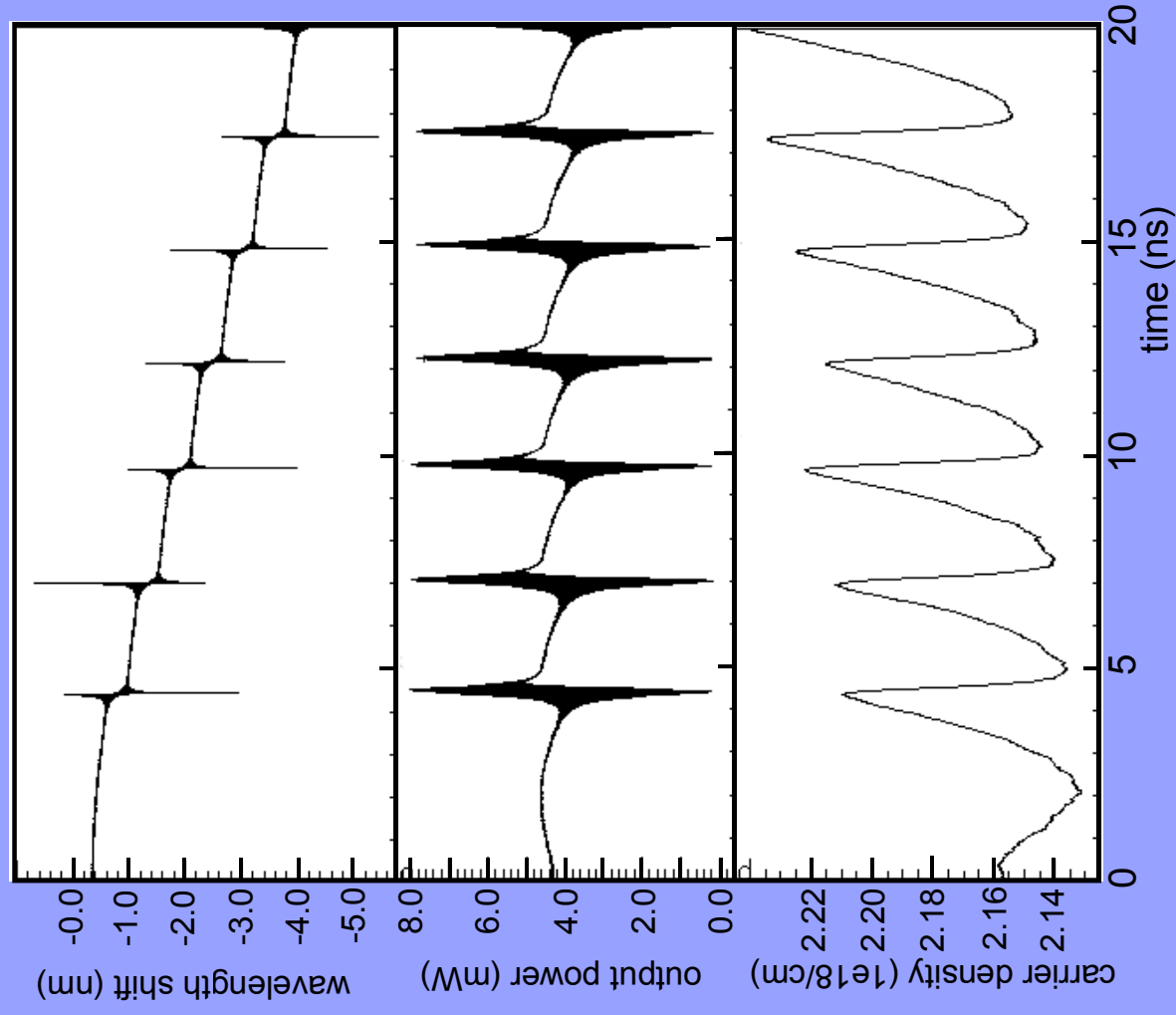
*“propagating ideas”*

**NUSOD-04**

Vary Only Grating A



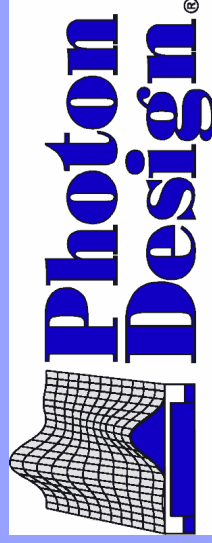
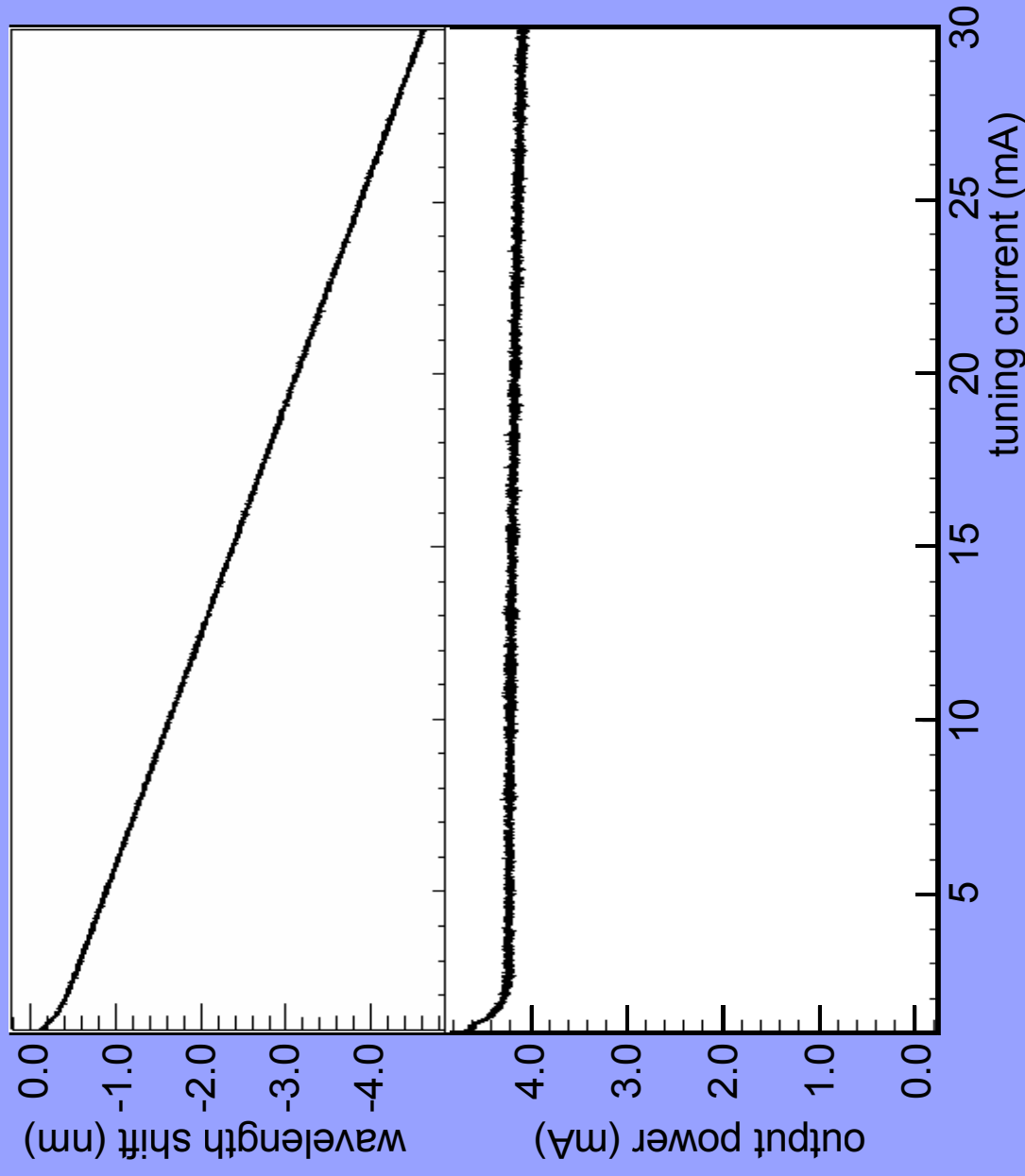
Vary Grating A and  
Grating B in Sync



*“propagating ideas”*

**NUSOD-04**

Vary both gratings  
and phase tuning  
sections

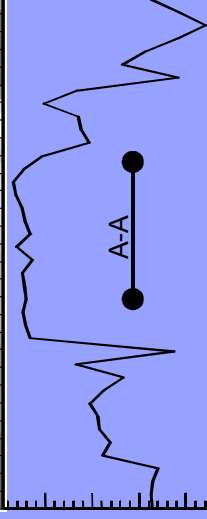
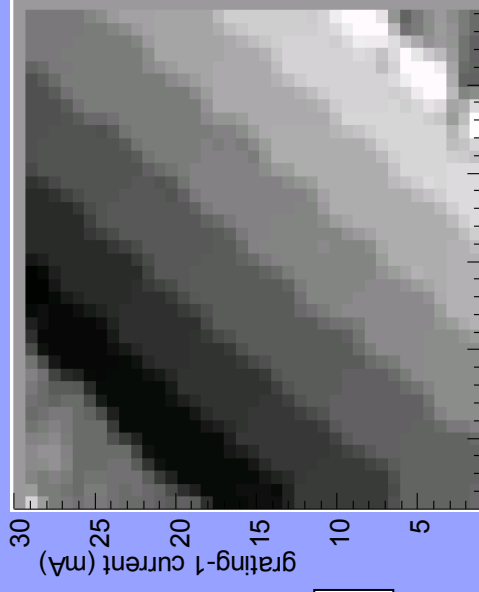


*“propagating ideas”*

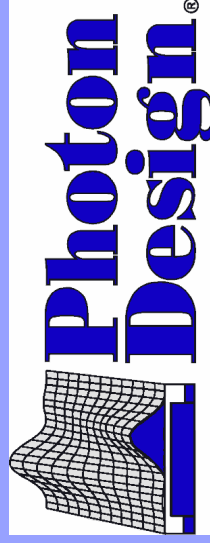
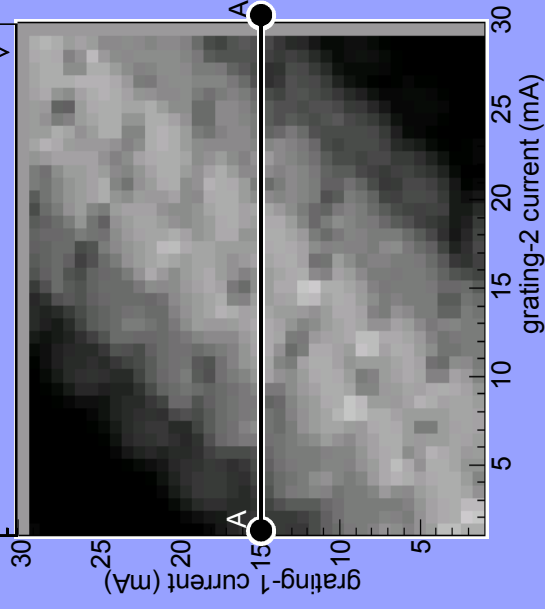
**NUSOD-04**

## Tuning Matrix

wavelength



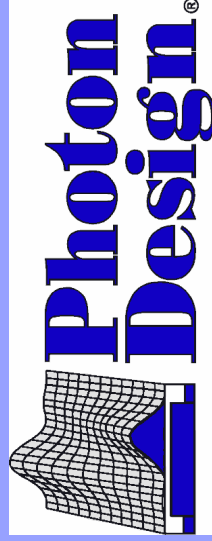
optical power



*“propagating ideas”*

**NUSOD-04**

The End



*“propagating ideas”*

**NUSOD-04**