

Efficient, Accurate Liquid Crystal Digital Light Deflector

Charles M. Titus, Philip J. Bos, Oleg D. Lavrentovich

Liquid Crystal Institute, Kent State University, Kent, OH 44242

Beam Steering Technologies

- Macroscopic motor-driven mirrors
- Acousto-optic Modulator
- Micromirror Technology
- Liquid Crystal Phase Grating
- Digital Light Deflection

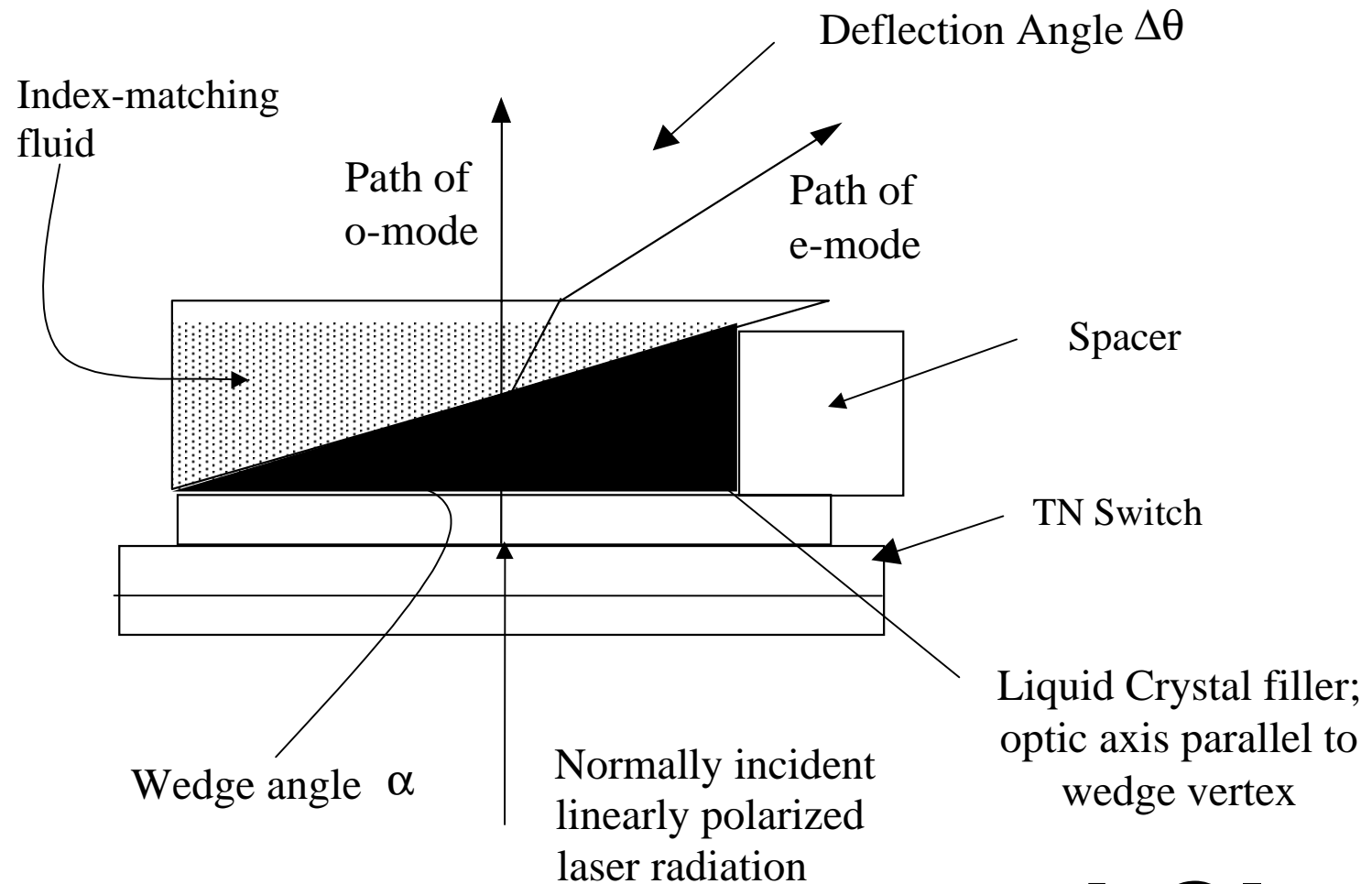
Each technology has its own unique advantages and disadvantages

Outline

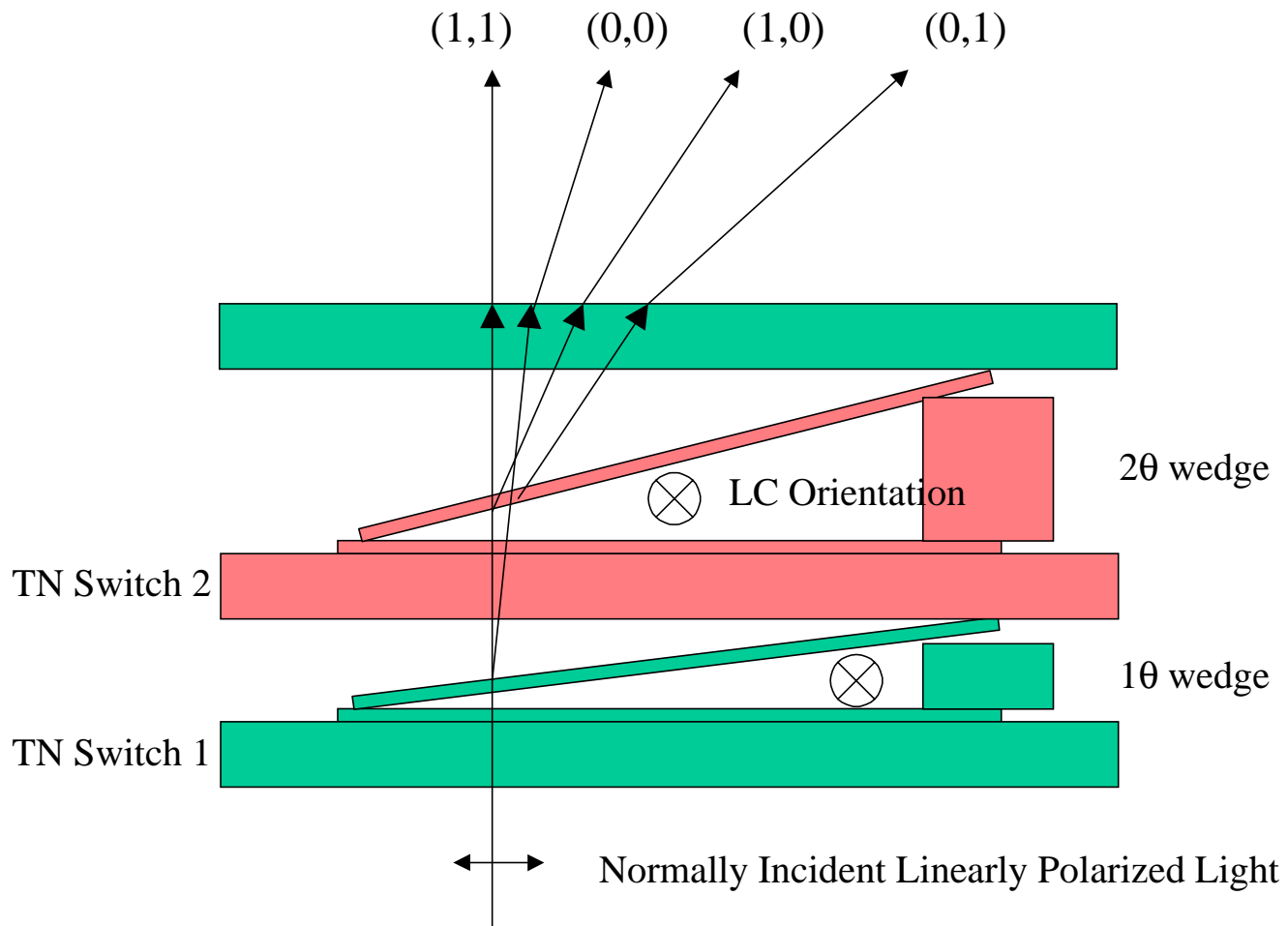
- DLD Description
- Scattering Losses: Material Story
- Device Accuracy: Design Story

Basic Binary DLD Switch

Polarization switch + Passive birefringent deflecting prism



Two-Stage DLD



Objective

One-dimensional DLD with:

- Liquid crystal - filled passive deflecting prisms
- Low-loss performance
- Angular separation: far-field divergence angle of laser
(0.001007 radians)
- Accurate Steering over angular range

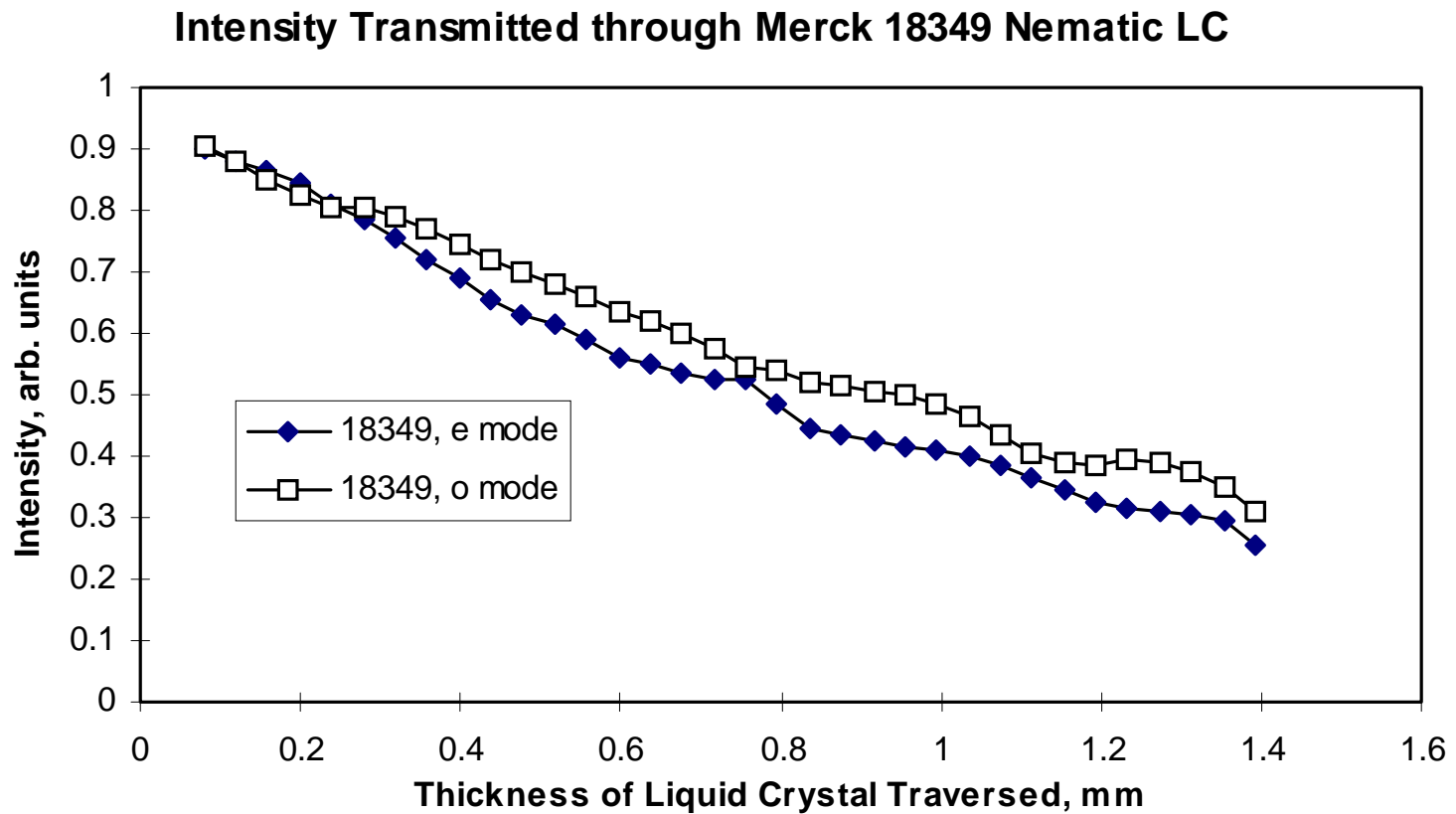
Material Story

- Problem #1: Inorganic crystals (e.g. calcite, $\Delta n \approx 0.18$) not easily, quickly machined to wide variety of prism angles
- Problem #2: Nematic liquid crystals scatter light

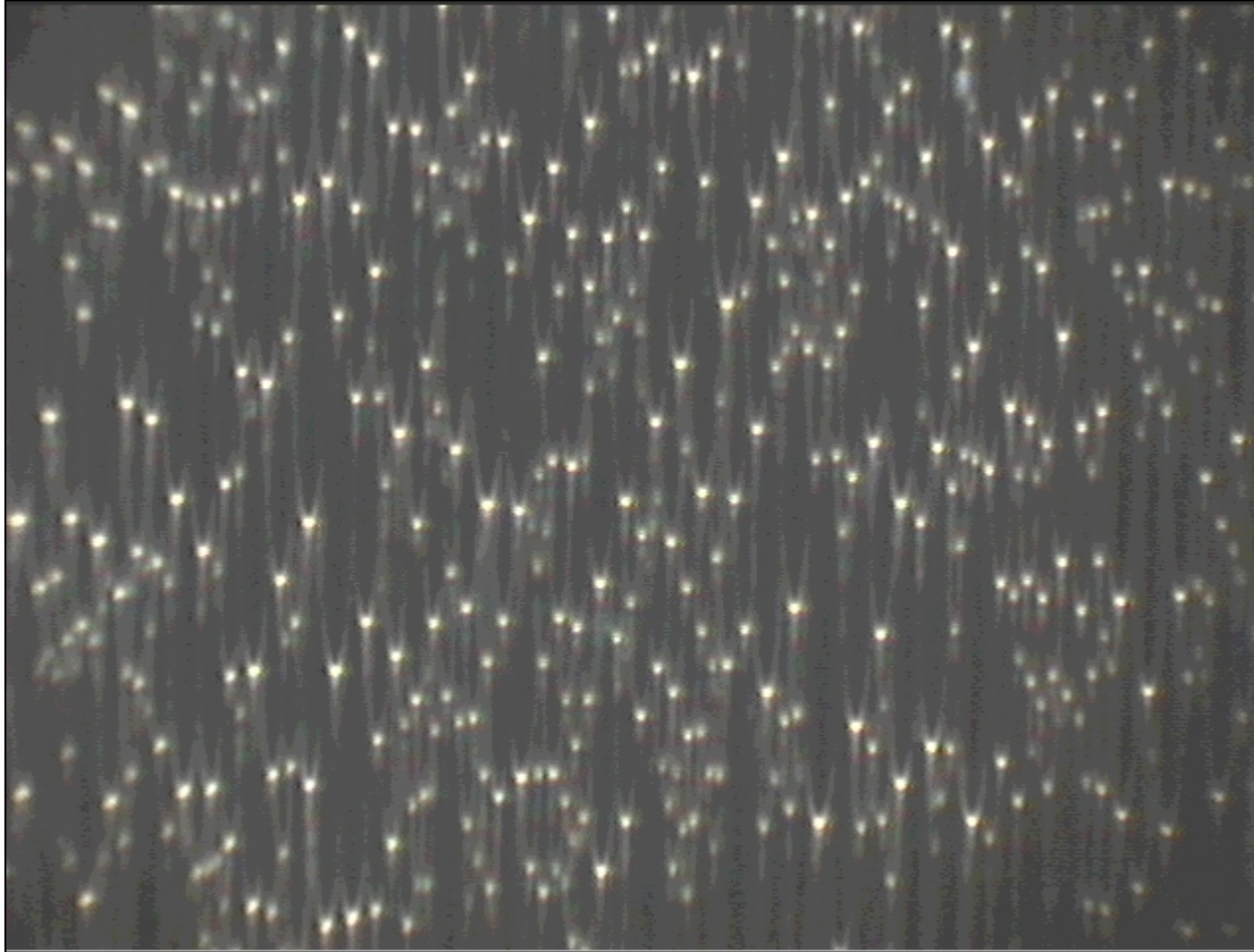
Solution Paths:

- Low Δn Nematic
- Crosslinkable Nematic
- Smectic-A Liquid Crystal

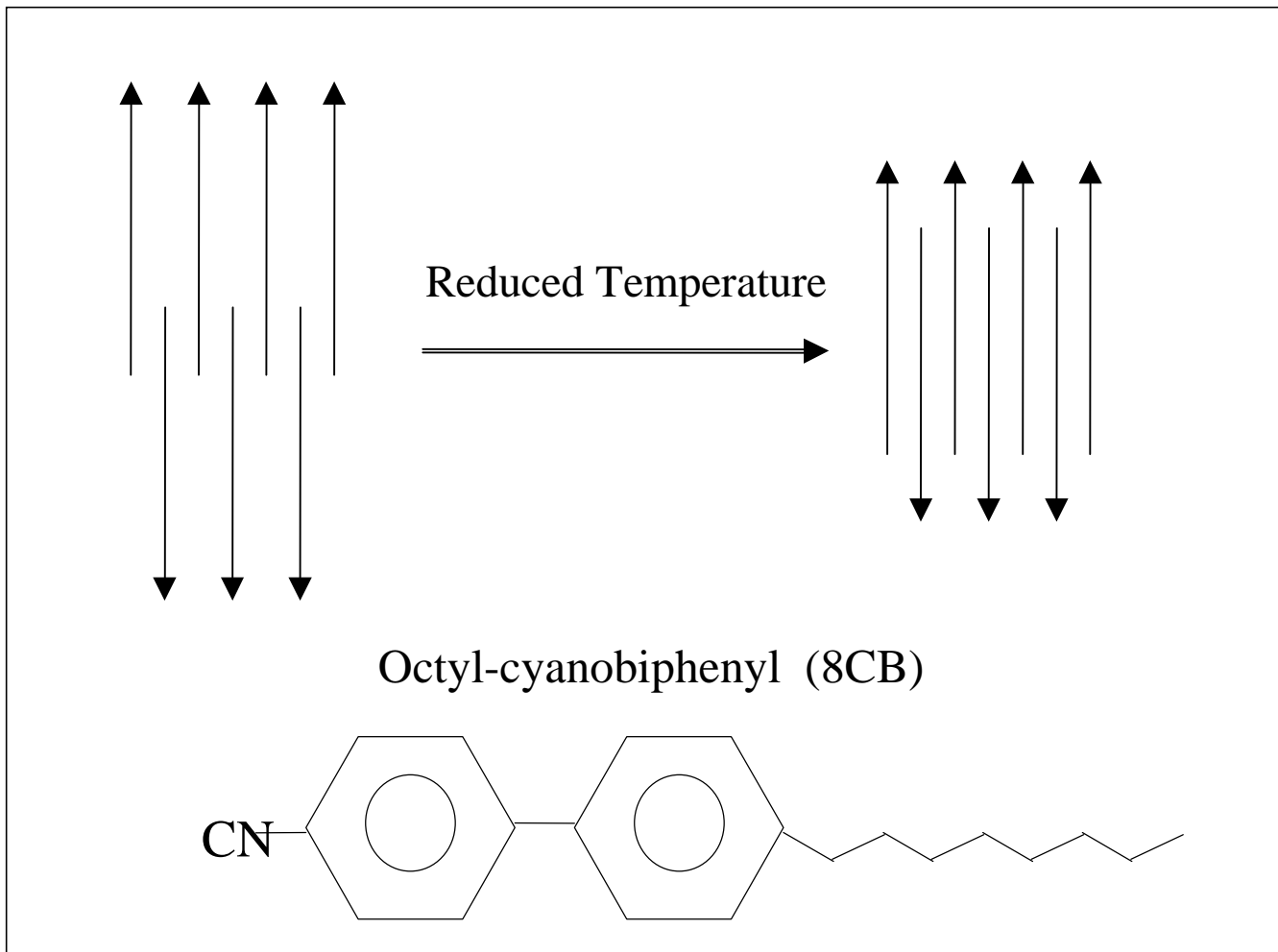
Scattering Losses - Nematic Liquid Crystal



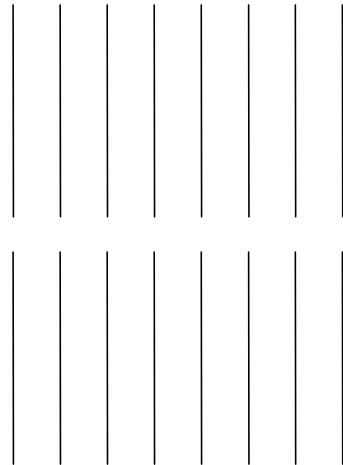
8CB Smectic A



Polar Smectic-A Liquid Crystal

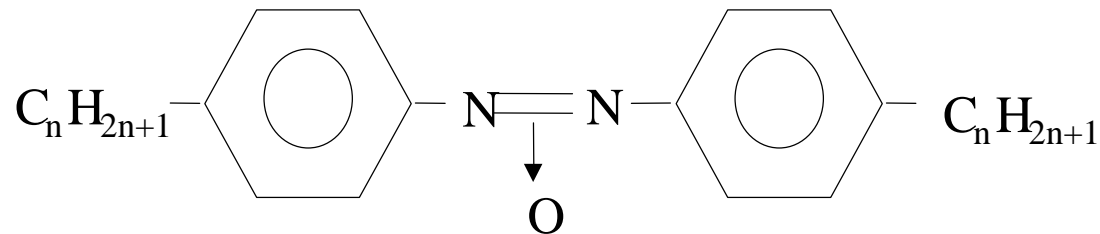


Nonpolar Smectic-A Liquid Crystal



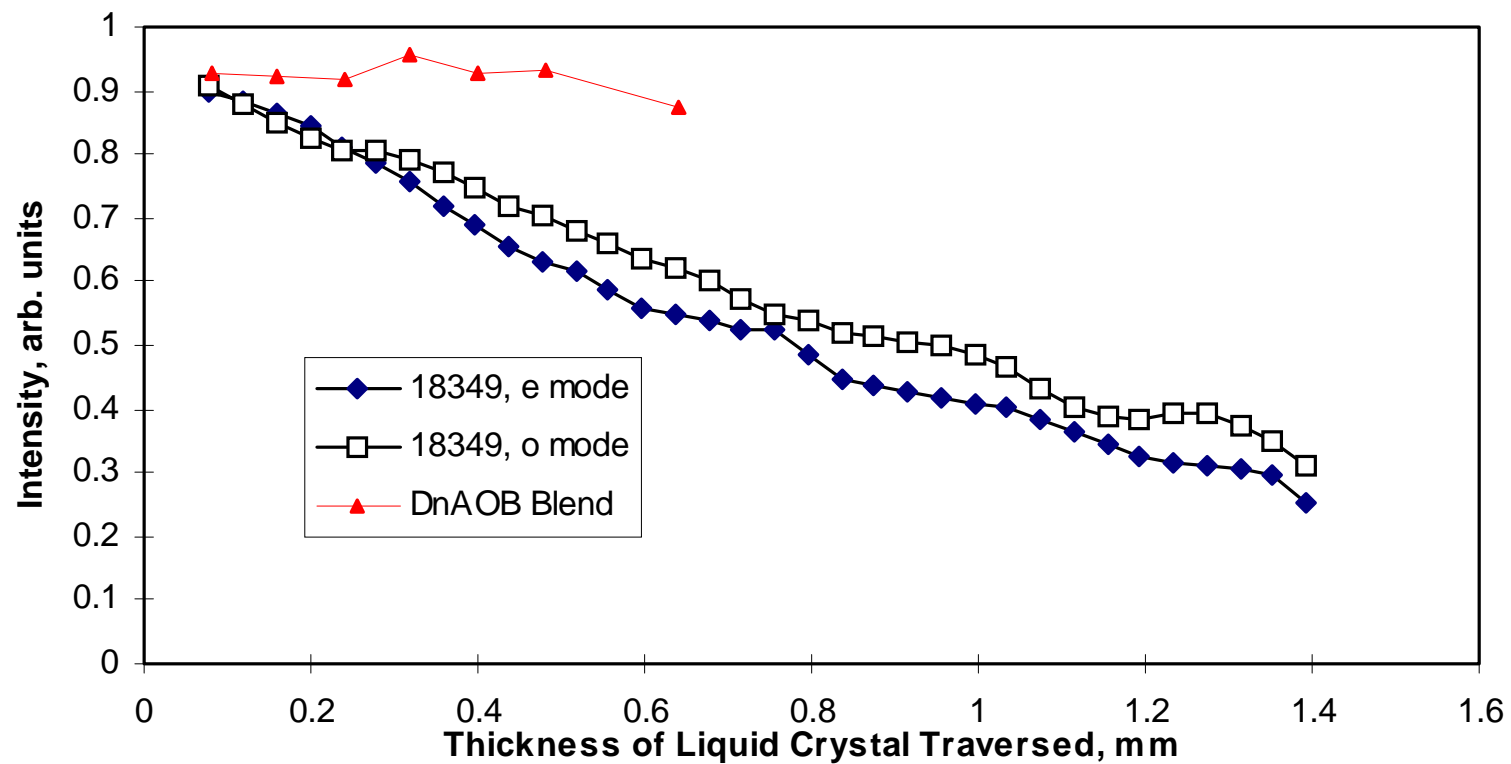
Monolayer
Smectic-A
Structure
Independent of
Temperature

Di-n-alkylazoxybenzene (DnAOB)



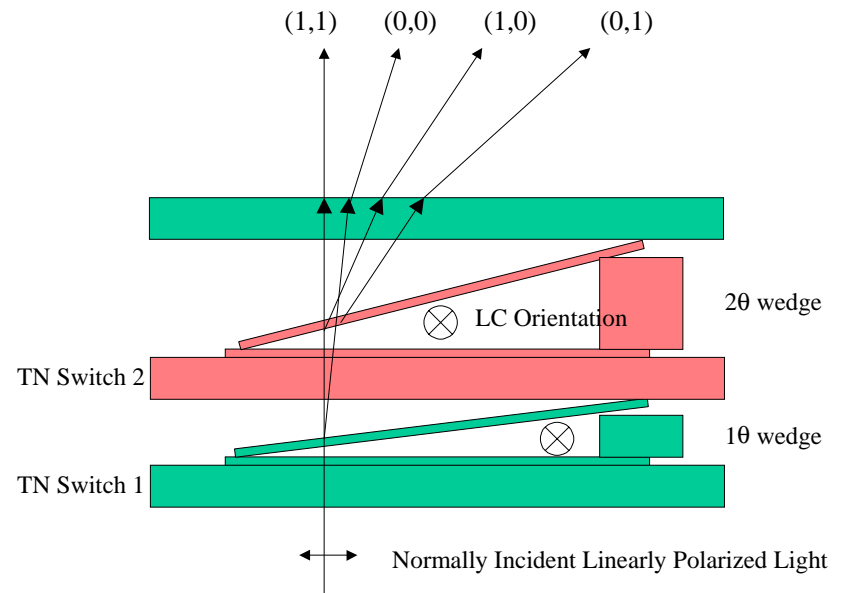
Nonpolar Smectic-A Liquid Crystal

reduced scattering losses



Design Story

- DLD “Accuracy” - constant angular separation of adjacent deflection paths over entire range
- Deflection paths determined by passive birefringent deflecting prisms

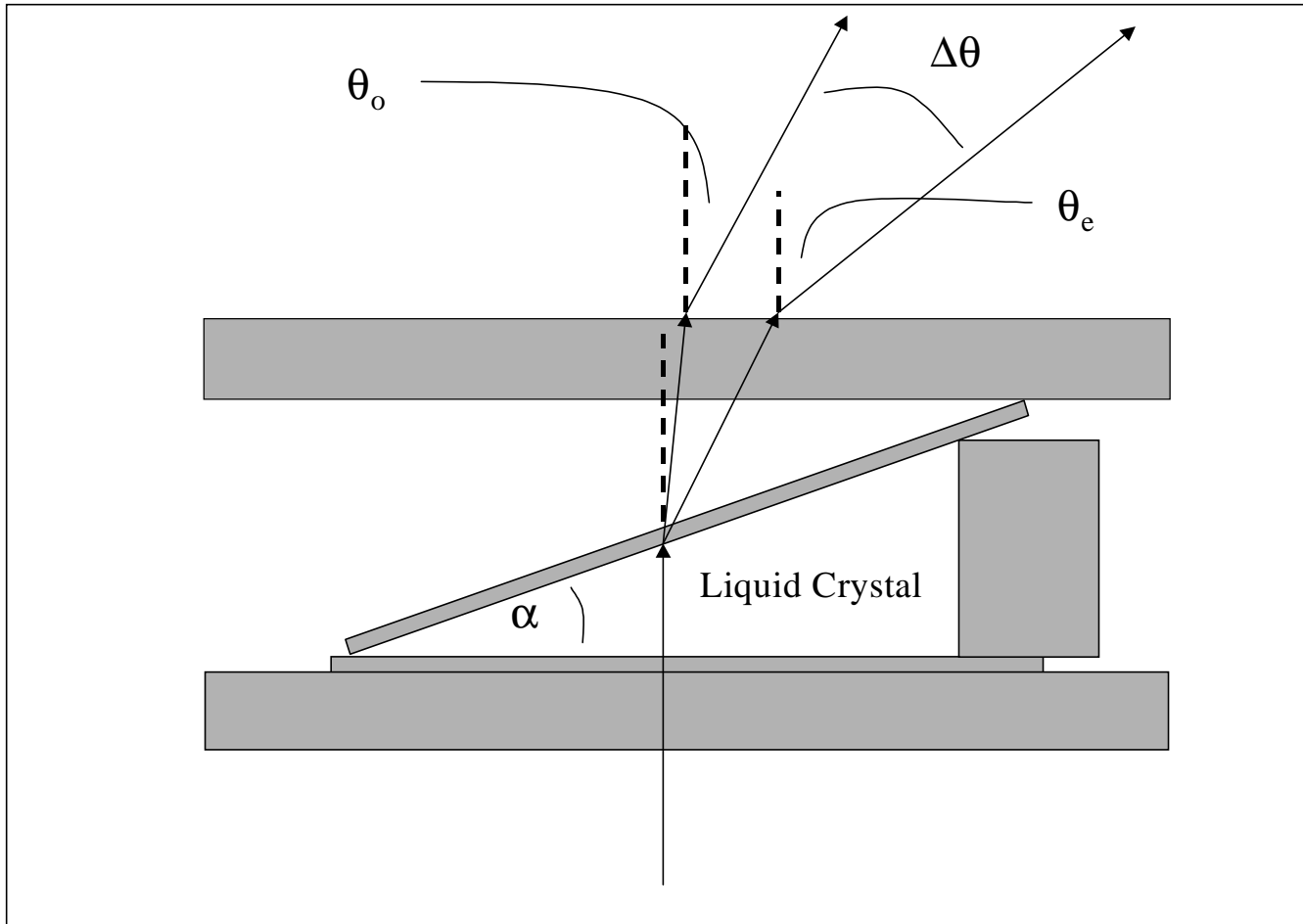


Design Approach #1: Treat each prism as isolated element

Design Approach #2: Each Deflection Path is influenced by all prisms in the composite DLD

Independent Prism Design

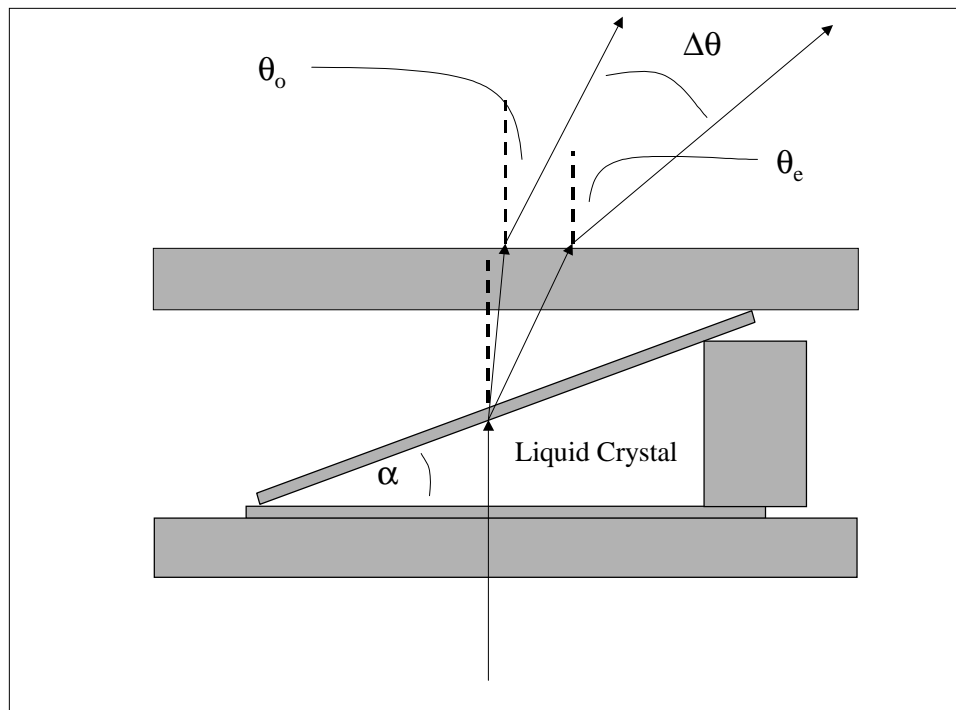
Based on Characteristic Angular Separation



Prism - Characteristic Angular Separation

Single Stage LC-DLD:

$$\Delta\theta_{exit} = \sin^{-1} \left\{ n_g \cdot \sin \left[\sin^{-1} \left(\frac{n_e}{n_g} \sin(\alpha) \right) - \alpha \right] \right\} - \sin^{-1} \left\{ n_g \cdot \sin \left[\sin^{-1} \left(\frac{n_o}{n_g} \sin(\alpha) \right) - \alpha \right] \right\}$$

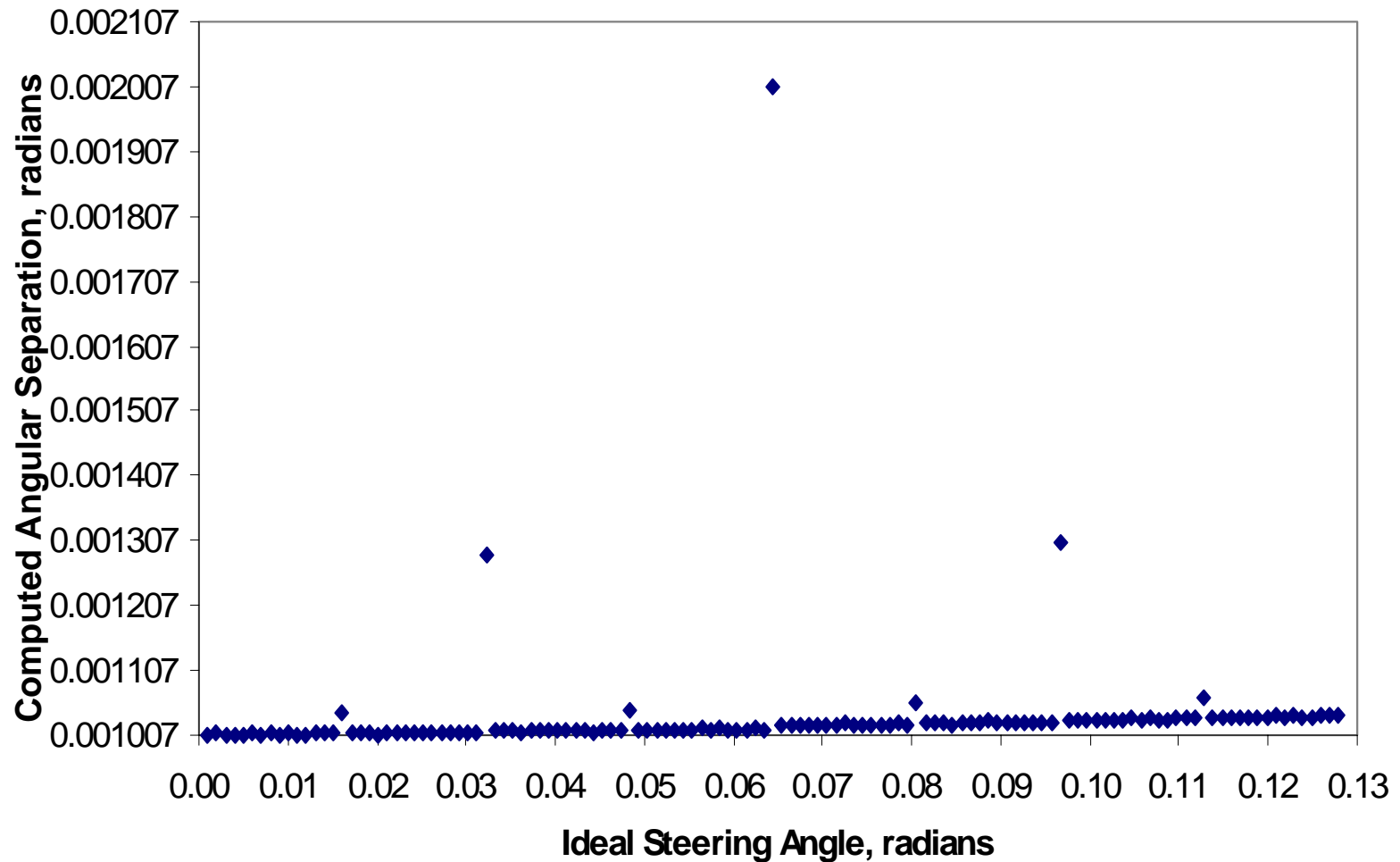


Small Angle
Approximation:

$$\Delta\theta_{exit} \approx \alpha \Delta n$$

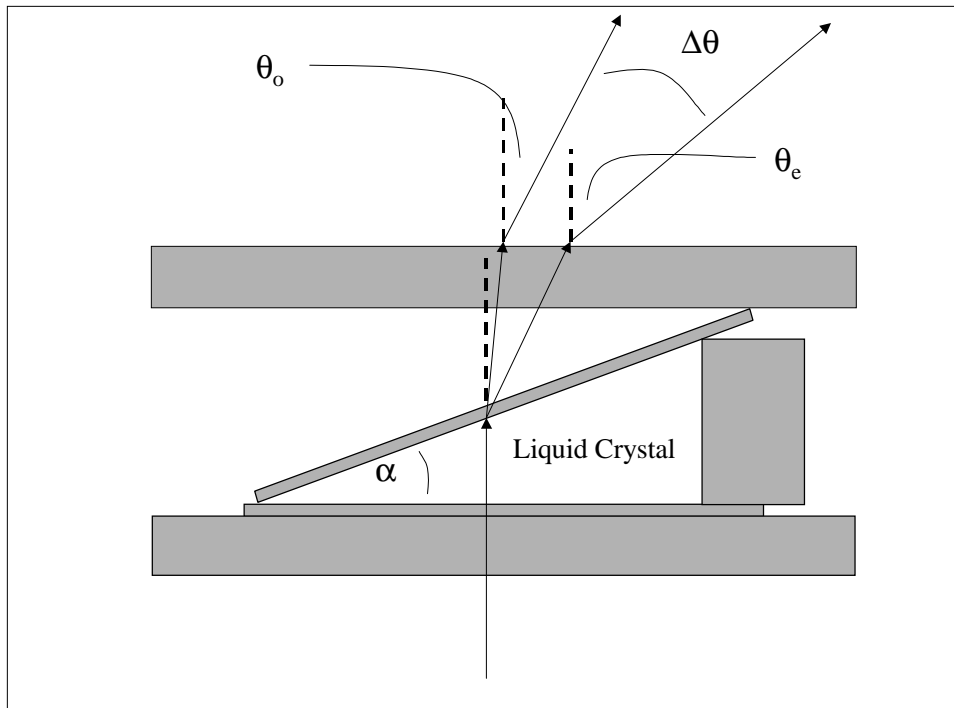
Use this for
“Sequence-Doubled”
Set of Prisms

Sequence-Doubled 7-Stage LC-DLD



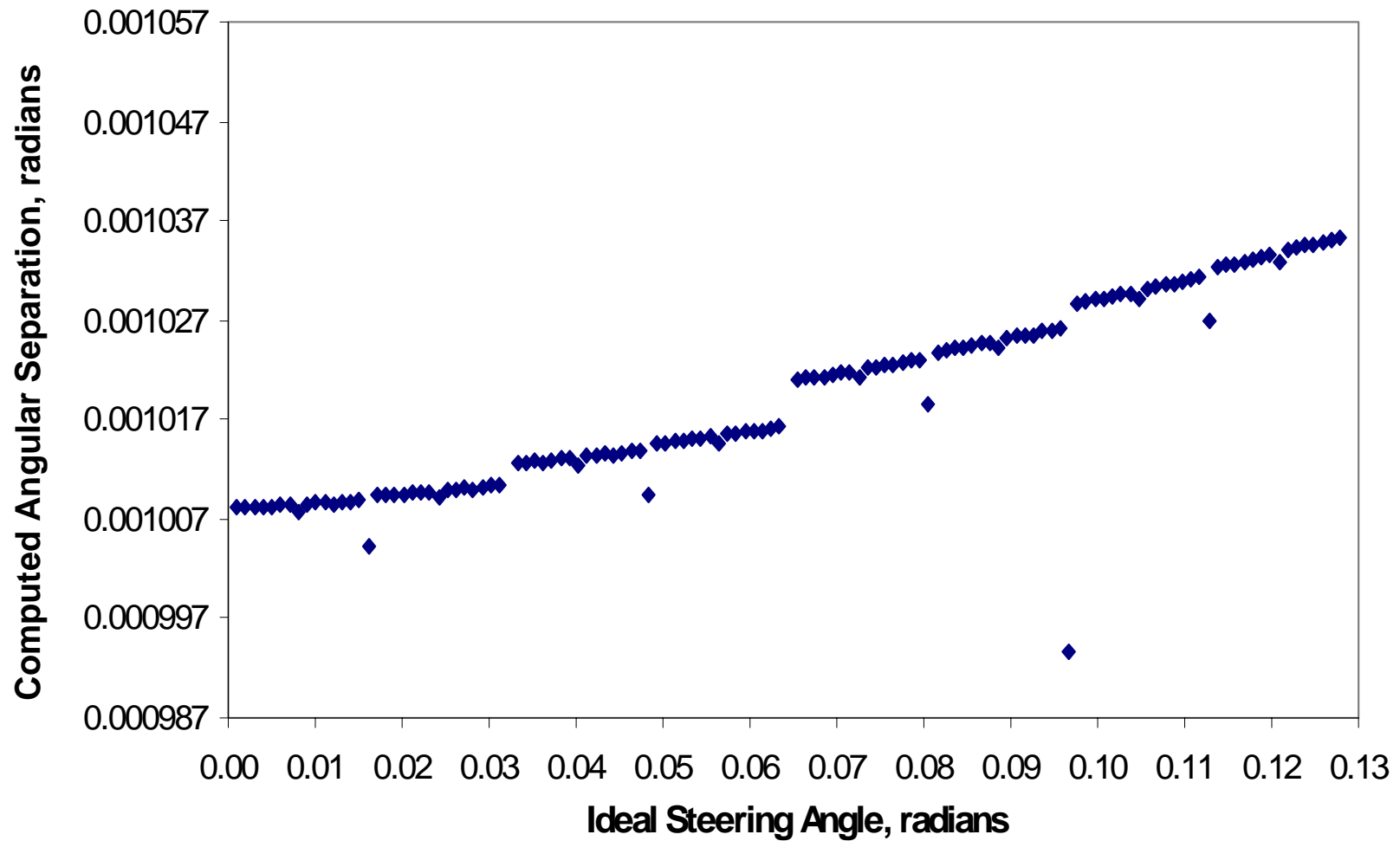
Prism - Characteristic Angular Separation

$$\Delta\theta_{exit} = \sin^{-1} \left\{ n_g \cdot \sin \left[\sin^{-1} \left(\frac{n_e}{n_g} \sin(\alpha) \right) - \alpha \right] \right\} - \sin^{-1} \left\{ n_g \cdot \sin \left[\sin^{-1} \left(\frac{n_o}{n_g} \sin(\alpha) \right) - \alpha \right] \right\}$$



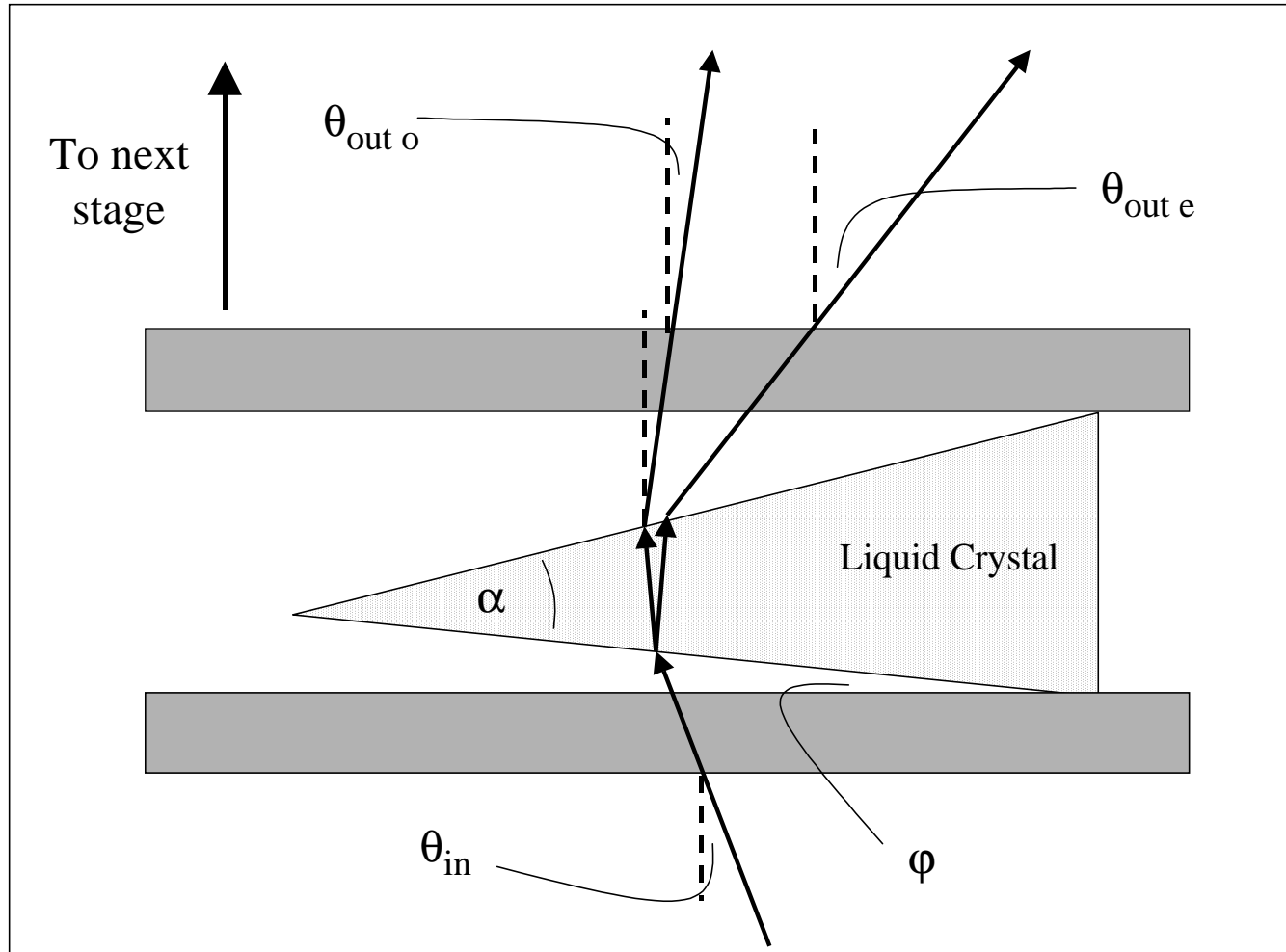
- Use this for “Nonlinear Sequenced” set of prisms...
- Use fixed-point iteration to solve for prism angle α
- Each prism calculated separately

Nonlinear Sequence 7-Stage LC-DLD



Integrated Design

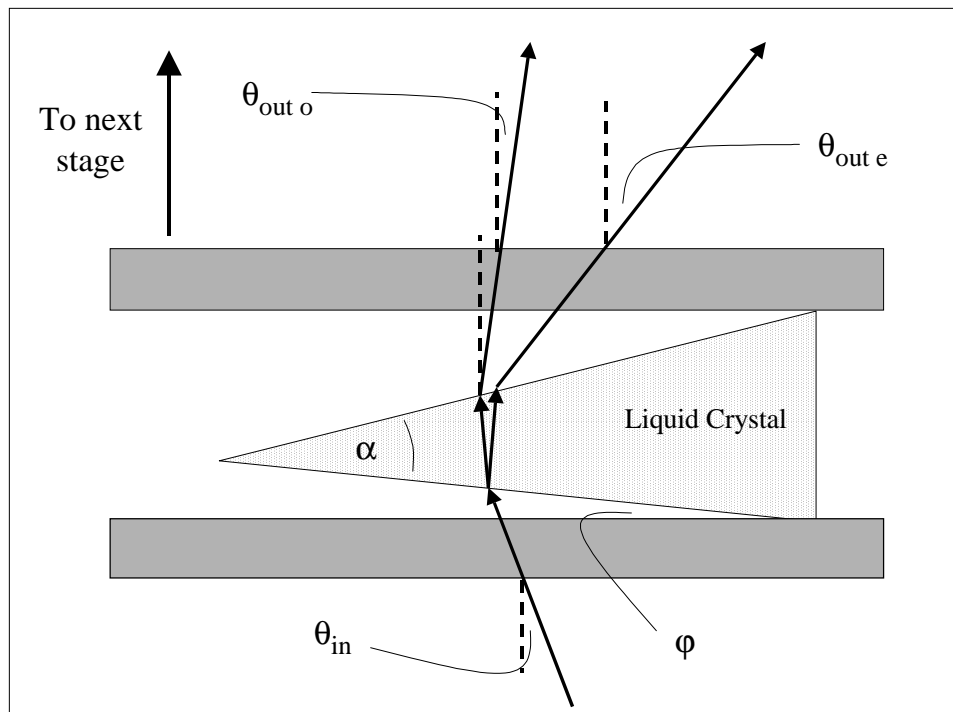
Each beam path influenced by *all* prisms



Integrated Design

Raytrace mapping function through one of the stages:

$$\theta_{out} = \varphi_j - \alpha_j + \sin^{-1} \left\{ \frac{n_{lc}}{n_g} \sin \left[\alpha_j + \sin^{-1} \left(\frac{n_g}{n_{lc}} \sin [\theta_{in} - \varphi_j] \right) \right] \right\}$$



Maps each path incident on a given stage into two output paths: ordinary and extraordinary mode traverses through prism

$$n_{lc} = n_o \text{ or } n_e$$

Integrated Design

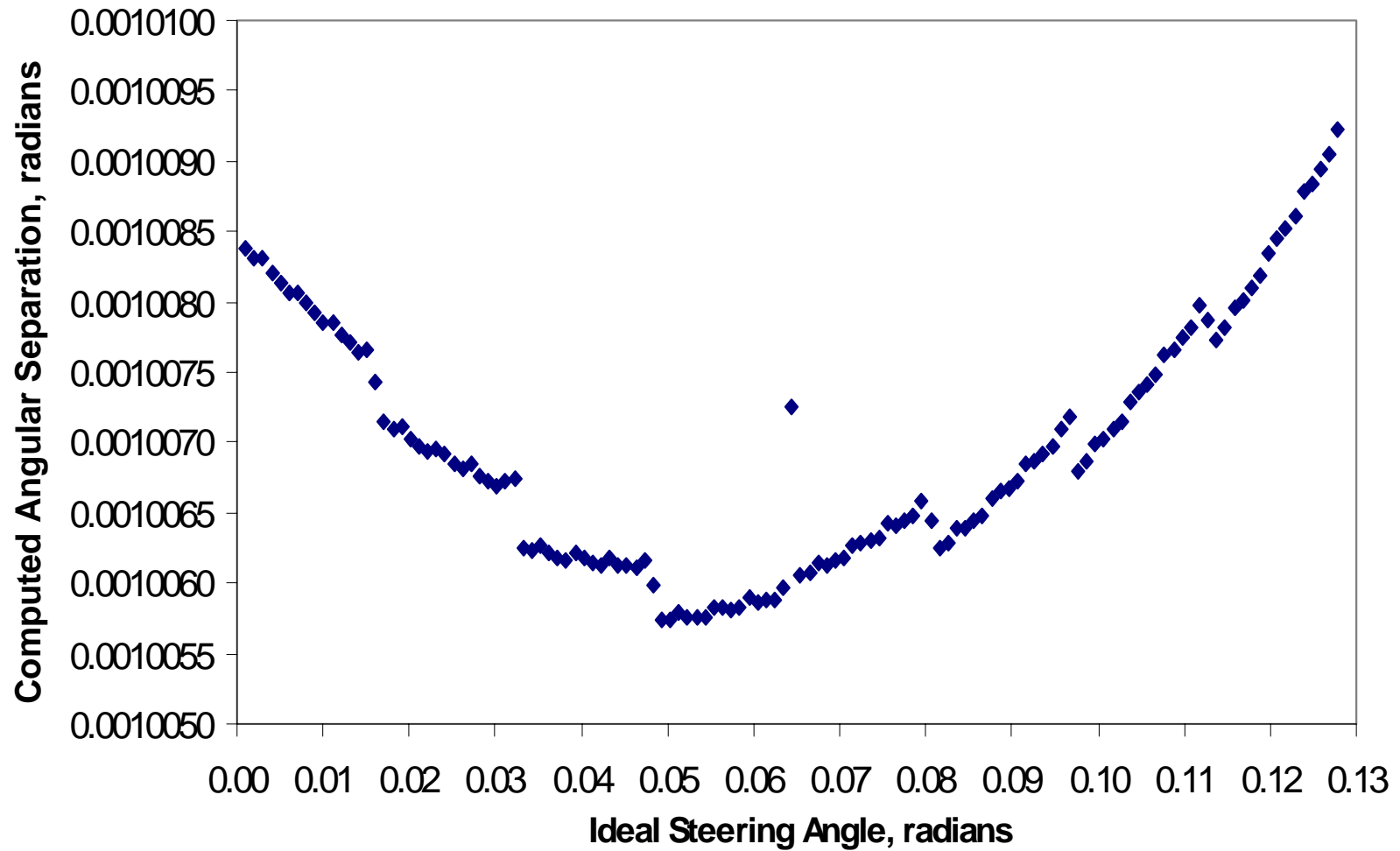
$$\theta_{out} = \varphi_j - \alpha_j + \sin^{-1} \left\{ \frac{n_{lc}}{n_g} \sin \left[\alpha_j + \sin^{-1} \left(\frac{n_g}{n_{lc}} \sin [\theta_{in} - \varphi_j] \right) \right] \right\}$$

- Map the single linearly-polarized incident beam through all N stages...Result: 2N output paths
- Upon exiting LC-DLD, angular separation of adjacent deflection paths:

$$\Delta\theta_{exit}^i = \sin^{-1} \left[n_g \sin(\theta_{out}^{i+1}) \right] - \sin^{-1} \left[n_g \sin(\theta_{out}^i) \right]$$

- Calculate RMS value of $\Delta\theta_{exit}^i - \Delta\theta_{ideal}$
- Minimize WRT all N values of prism angles α and prism tilts φ (requires numerical multi-variable minimization method)

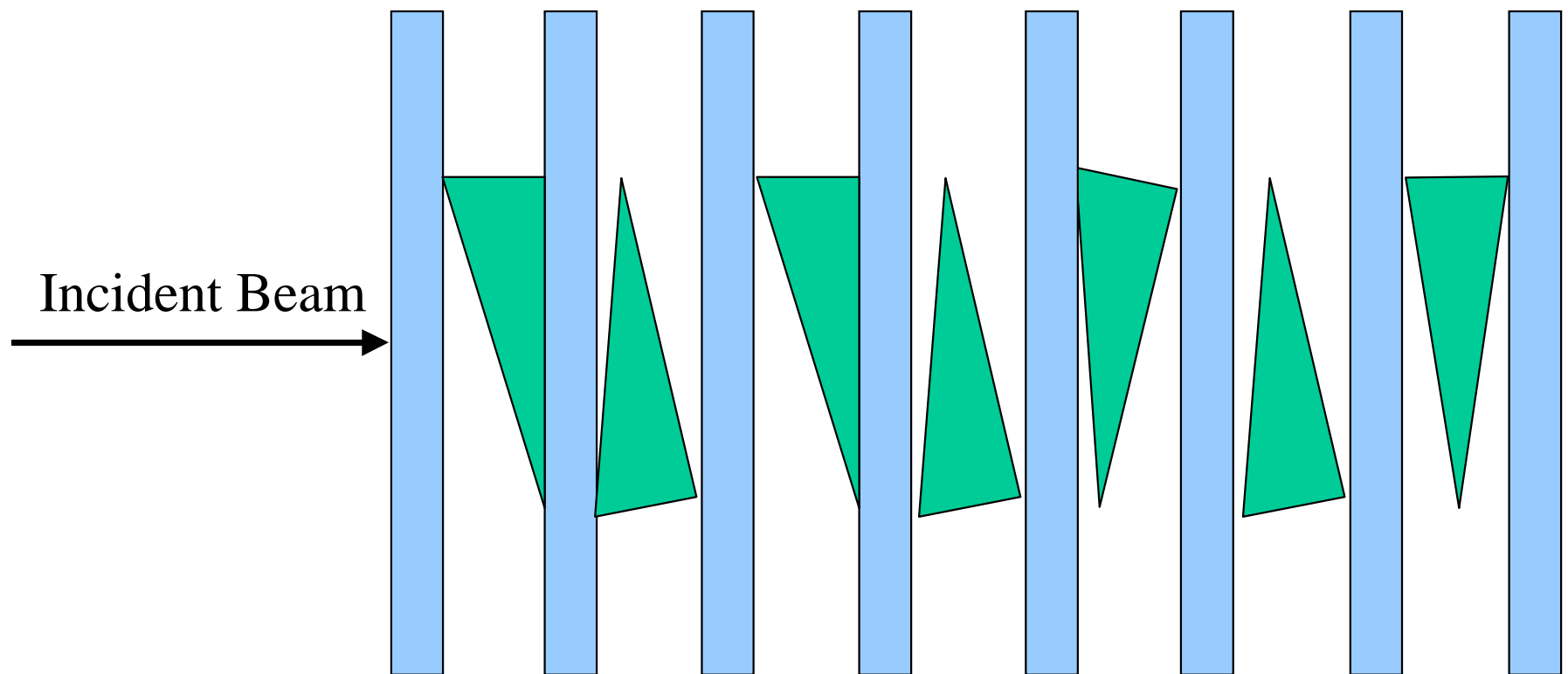
Integrated Design 7-Stage LC-DLD



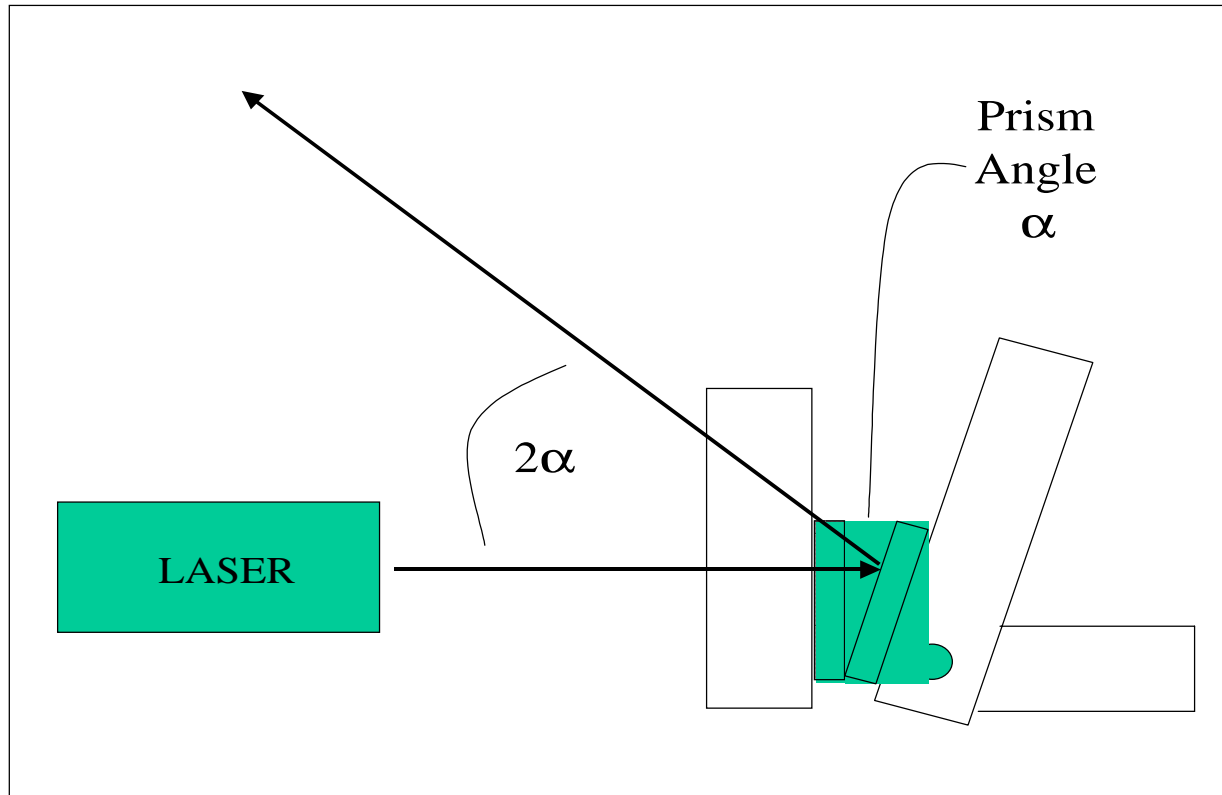
Design Results - 3 Approaches

Stage Number	n_o	n_e	Sequence Doubled Wedge angle α , radians	Nonlinear Sequence Wedge angle α , radians	Integrated Design Wedge angle α , radians	Integrated Design Wedge tilt ϕ , radians
1	1.4746	1.5183	0.02304	0.02304	0.02302	0.02299
2	1.4746	1.5183	0.04609	0.04605	0.04603	0.03889
3	1.52	1.72	0.02014	0.02014	0.02012	0.02012
4	1.52	1.72	0.04028	0.04025	0.04024	0.01237
5	1.52	1.72	0.08056	0.08034	0.08039	0.06634
6	1.52	1.72	0.16112	0.15939	0.16046	0.05410
7	1.52	1.80	0.23017	0.22482	0.22860	0.13648

Integrated Design LC-DLD



Prism Fabrication Apparatus



Resolution 0.0005 to 0.001 radian

Conclusions

- Improved Liquid Crystal Filler for Deflecting Prisms:
Nonpolar, Monolayer Smectic A
- Increased Accuracy over Wider Angular Range:
Error Minimization Design Method

Future Work

- Further increase angular range:
multi-wedge stage design
- Experimental:
rebuild in progress, measurements will be reported soon

Acknowledgements, Etc.

Dr. Satyendra Kumar: help with smectics

Dr. Mary Neubert, Julie Kim: synthesis

For more information on current and future liquid crystal beam steering research at Kent State University's Liquid Crystal Institute, contact:

Dr. Philip Bos, pbos@kent.edu

[Charles M. Titus, cmmt@columbo.kent.edu](mailto:cmmt@columbo.kent.edu)