Liquid Crystal Based Optical Phased Array for Steering Lasers

Application Area:	IRCM
Key Technology Elements:	Steering Method and Pointing and Tracking
Technology Areas:	Liquid Crystal, Optical Phased Array
Lead Organization:	Liquid Crystal Institute, Kent State University

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BNS BOULDER NONLINEAR SYSTEMS, INC.

Introduction

Outline

- Background
- Our Basic Approach
- The Team
- Tasks & Time Line

Background

- The Goal
- Previous work

The Goal

- Steer MWIR over wide angles, with better than 100μrad resolution, and with 1rad/sec slew rate.
- Replace existing gimbal with something light, conformal and inexpensive

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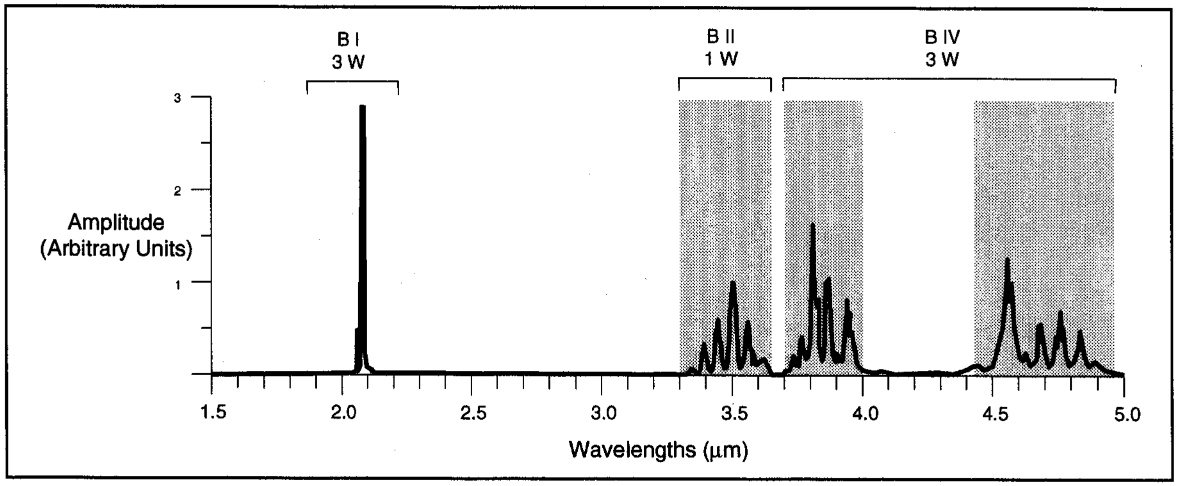
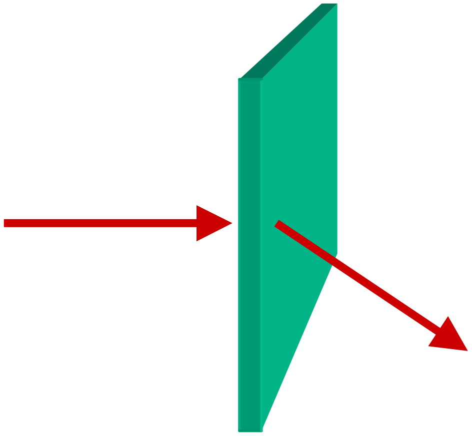
Goal

- Steer this spectra



- With Something that looks like:



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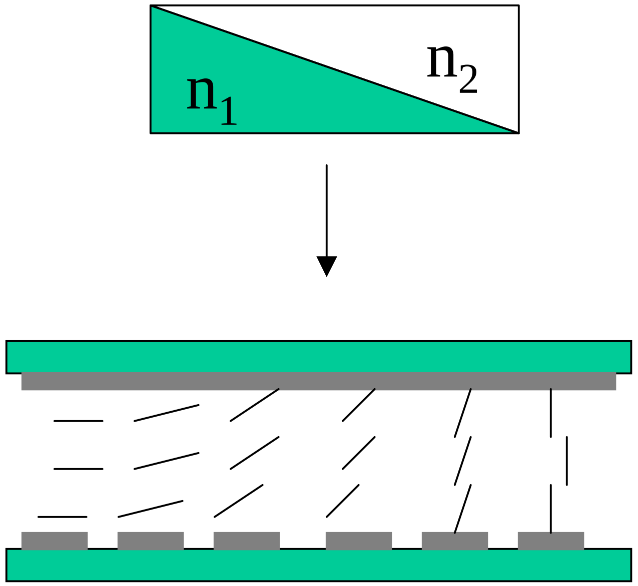
Previous Work

- OPA devices
- De-centered Lenses

Optical Phased Arrays

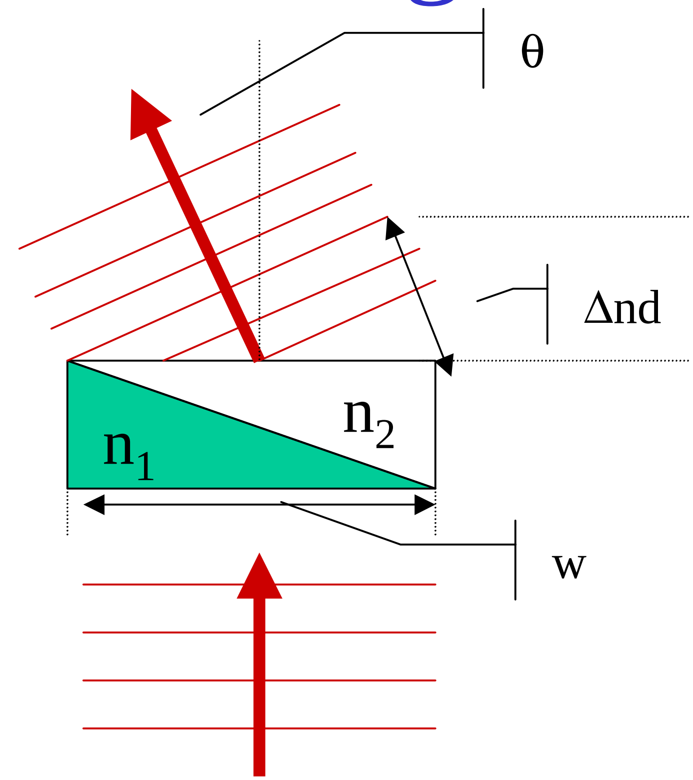
- Segmented Electrodes that apply voltages that change the orientation of the LC director, and provide a ramp in the index of refraction

- Works well for small angles,but for large angles has problem of slow switching.



Problem of Slow Switching

- Consider an LC Prism
- Large steering angle requires a large d
- Speed of a LC device is proportional to d^2 .



$$\sin\theta = \Delta nd / w$$

If θ is 10 degrees and
w is 2.5 cm, Δnd must be
4480 microns, So d about
25,000 microns

Typical 5 micron LC cell relaxes in about 10 ms,
So 25,000 micron cell would relax in about 70 hours.

Optical Phased Arrays

- "resets" offer a solution to this problem for monochromatic light, but the IRCM application has a wide bandwidth.

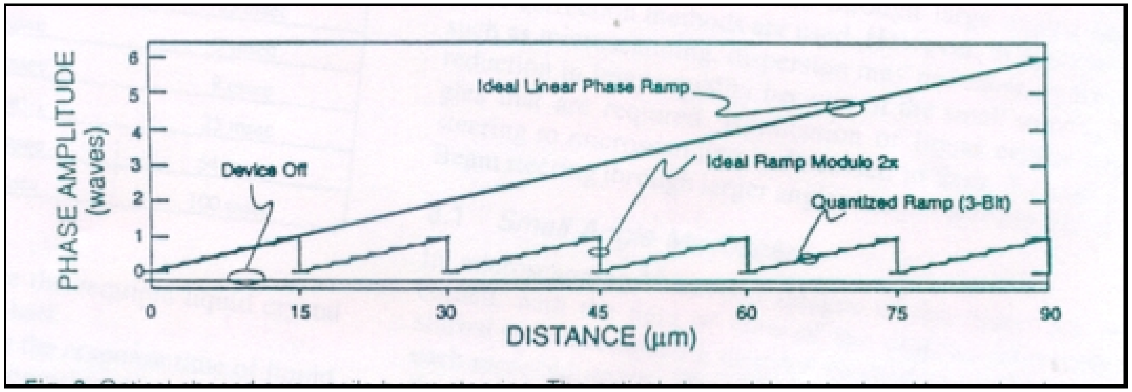


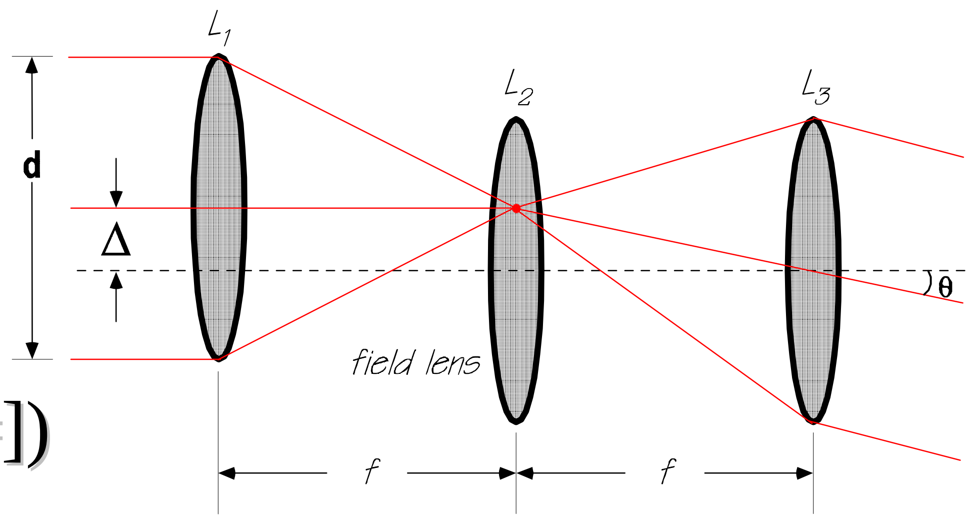
Figure 1 - "Resets" at Path-Length Retardation of One Wave (P. McManamon, E. Watson, T. Dorschner, L. Barnes, Opt Eng 32 p2657, 1993)

Decentered Lenses

- $\tan(\theta) = \Delta/f$

  $\Delta_{max} = d/2$
- $f/\# = f/d$

Thus, $\theta_{max} = \tan^{-1}(0.5/[f/\#])$

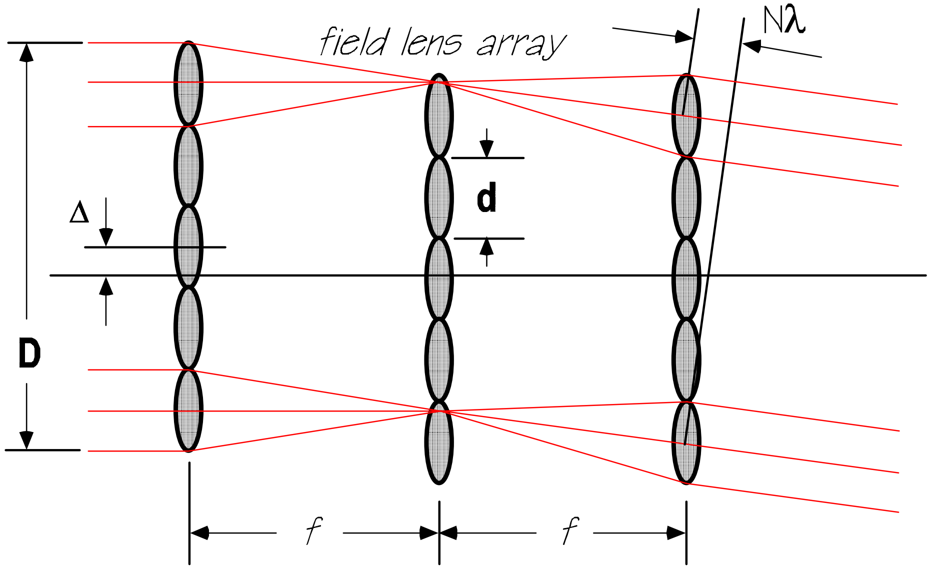


- Examples:
  - if $\theta_{max} = 30°$, then f/# = 0.86
  - if $\theta_{max} = 1°$, then f/# = 28.65
  - if f/# = 10°, then $\theta_{max} = 2.86°$

Issues are that these can be a little bulky and difficult to position with accuracy required for this application

Micro-Lens Arrays

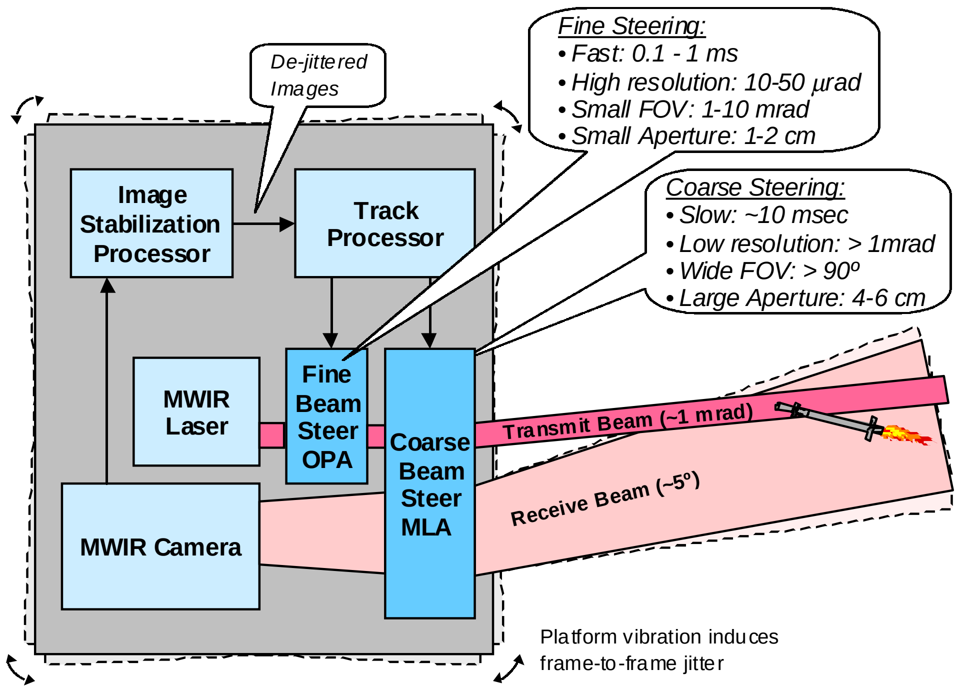
- Micro-Lens Arrays have also been Considered



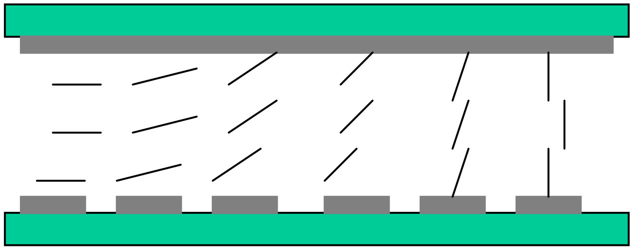
If size of array is small, can have significant diffractive effects that are problematic for wide bandwidths.

Our Basic Approach

- Wide Angle Steering with De-centered Lenses
- Fine Angle Steering with and OPA device

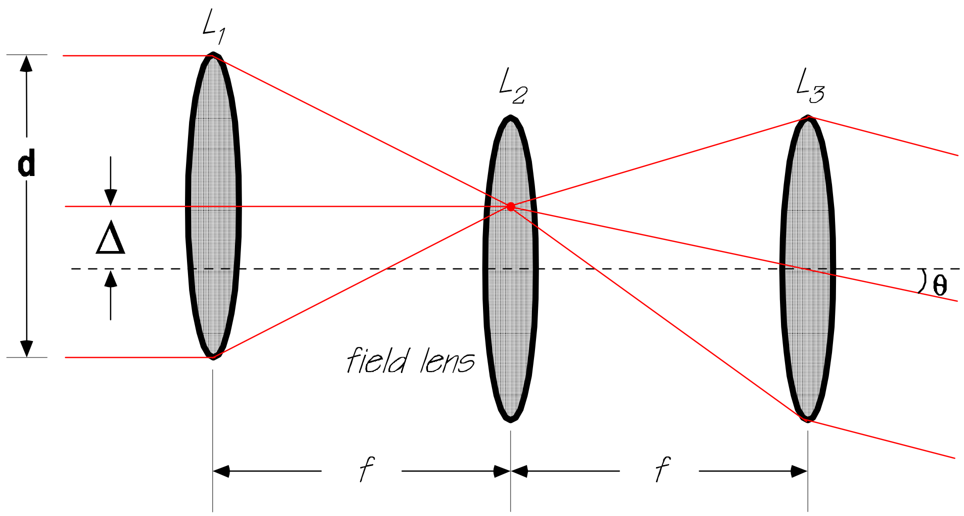


Fine Angle Steering



- OPA w/o Resets
- Very Simple
- If max angle is 1mrad, and w= 1 cm, total cell thickness is about 50 microns
- Above yields a switching speed of about 1 second for a single cell at room temp.

Wide Angle Steering



- $\tan(\theta) = \Delta/f$

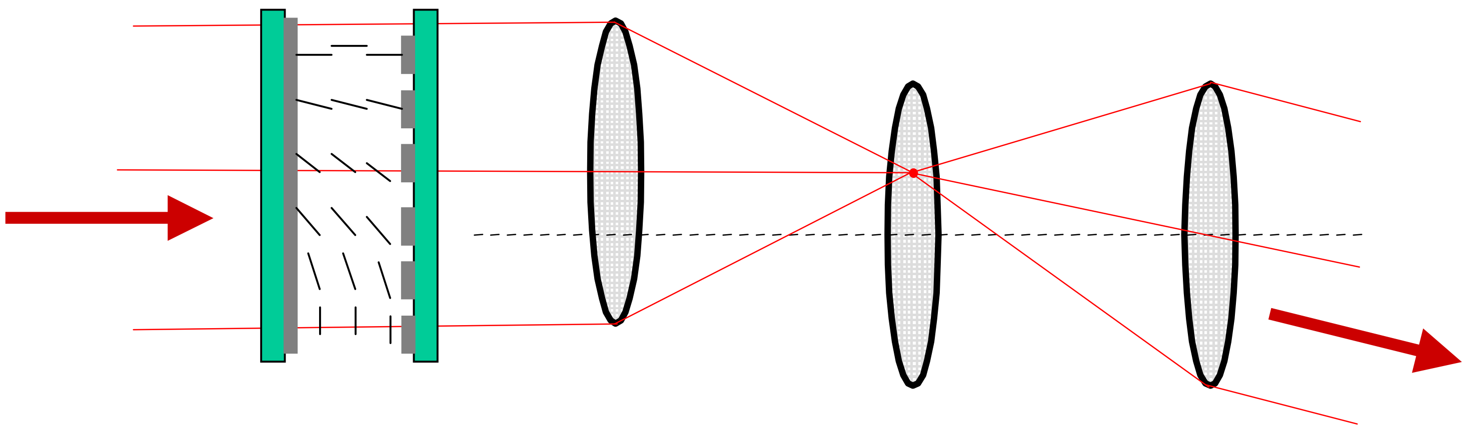
  $\Delta_{max} = d/2$
- $f/\# = f/d$

Thus, $\theta_{max} = \tan^{-1}(0.5/[f/\#])$

If have d = 2.5 cm,
with f/# = 1:
Max angle is 26 degrees
and can have accuracy
of 0.001 radians using
a translator with 25micron
resolution ($1K)

The approach is conformal, cheep, and easy for angles between 1mrad and 1/2 rad

Basic Approach



- Uses De-centered lens approach for large angles (cheep, easy, conformal)
- Uses Simple, “ reset-less” OPA for fine angles (non-mechanical device, fine resolution is easy, cheep, conformal)

Issues with Basic Approach

- Speed of OPA device
- Wavelength dependence of all components
- IR transmission of all components
- Weight of Lenses.
- Aperture Size of Lenses
- Max angle of de-centered lens approach
- Optimization of System Design

The Team

- Lockheed Martin
- University of Dayton
- Boulder Non Linear Systems
- Kent State University

Lockheed Martin

Naval Electronics & Surveillance Systems-Akron

(LM NE&SS-Akron)

- Define System Issues
- Maintain eye toward end result

Lockheed Martin

- Previous Projects
  - Project: Multi-band Anti-ship Cruise Missile Defense Tactical Electronic Warfare System (Navy, 1992-1996)
  - Project: Mid -IR Laser IRCM Systems Support (TRW subcontractor, DARPA (1995 -1997)
  - Project: Laser IRCM Flyout Experiment (Air Force, 1994 - 2000)
  - Project: IR Acquisition Experiment (SAIC Subcontractor) (1993 - 1995)

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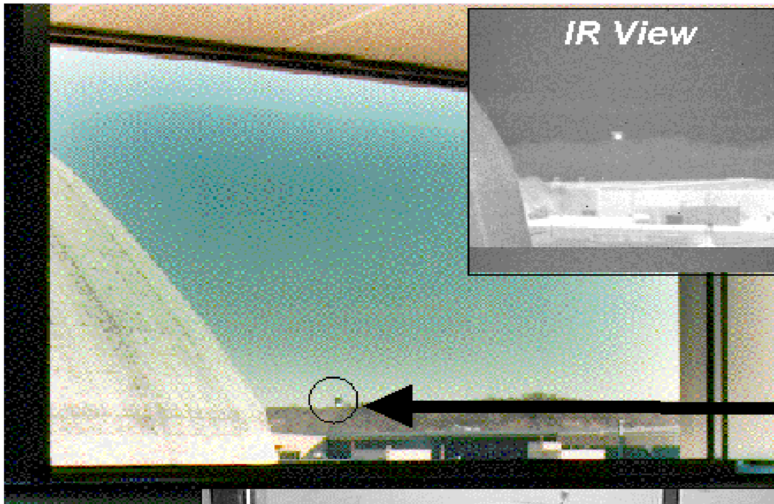
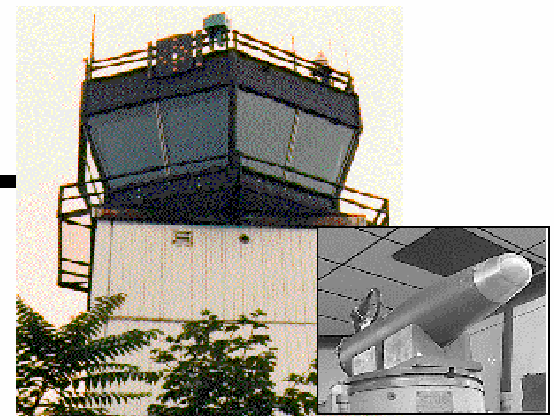
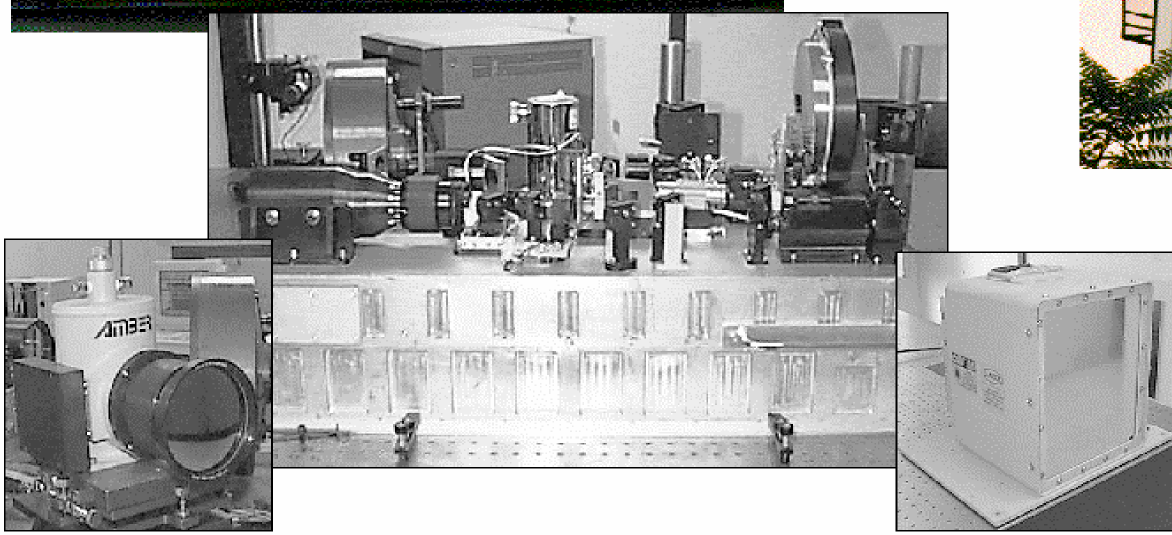
View from IRCM Lab to Tower



LMTDS-Akron Test Facilities
- 1.6 km Open Air Range
- Development/Integration Testing
- Factory Acceptance Testing



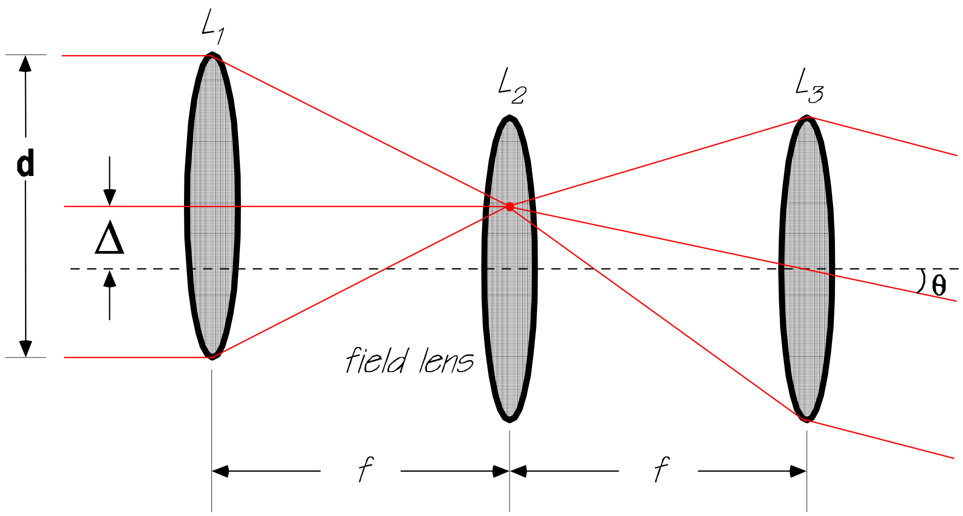
Test Tower w/Seekers



IR Camera, Laser, IR Source

University of Dayton

- De-centered Lens Design



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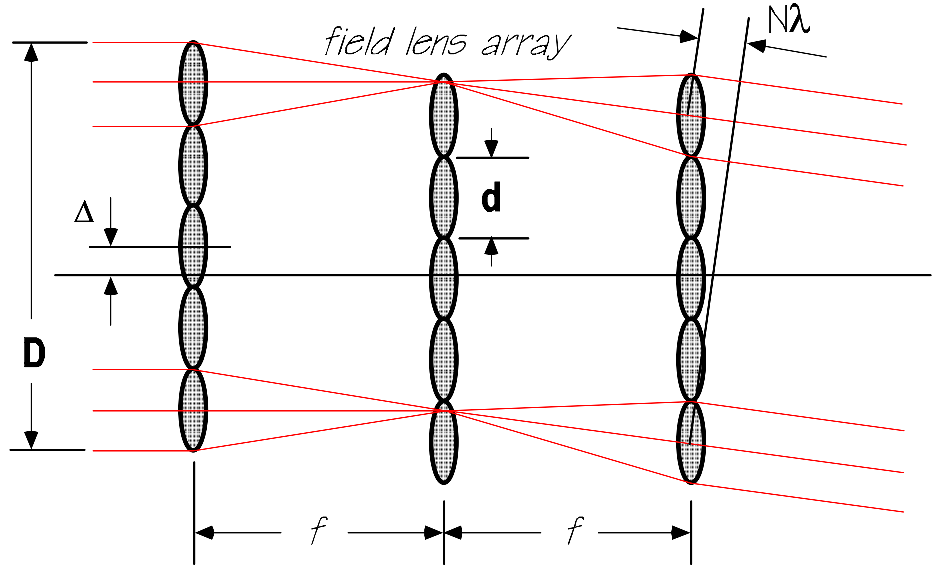
- Previous Project
  - Micro-lens Array Calculations (AFIT)



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- OPA Fine Steering Unit
- Cell, considering IR absorption, and wavefront distortion
- Multi-cell module with computer interface

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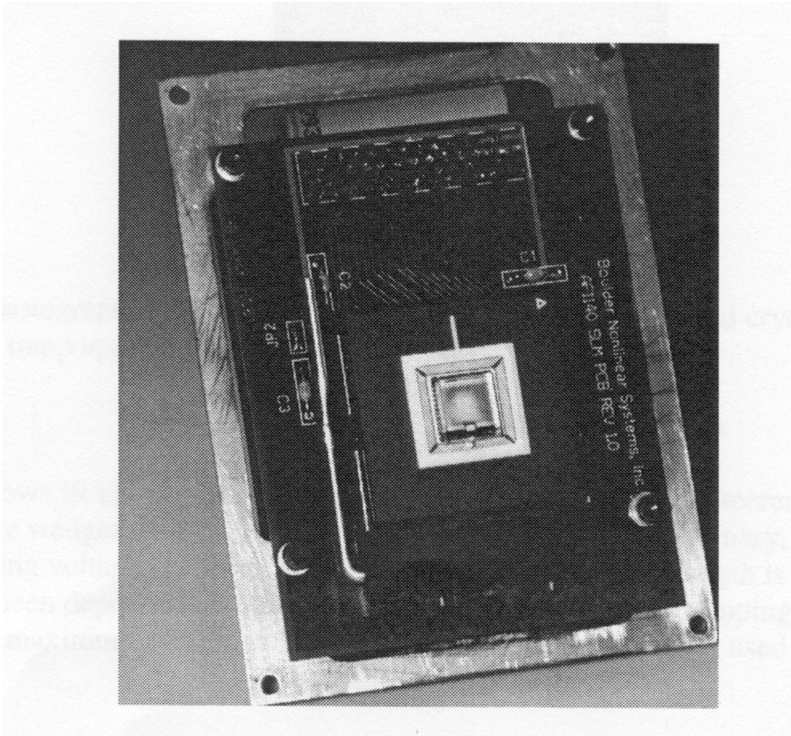
Boulder Non Linear Systems

- Optical Head for LCOS OPA beamsteerer
  - VLSI based
  - 4096 1micron lines
  - 128 angles



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- Technical Approach Definition
- OPA E/O Design
  - Compare candidate approaches
  - Provide E/O materials appropriate for mid-wave application
- Project Management and Reporting

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- Previous Projects
  - Beam Steering Devices (AFOSR)
  - Advanced Liquid Crystal Optical Materials (NSF, Science and Technology Center)

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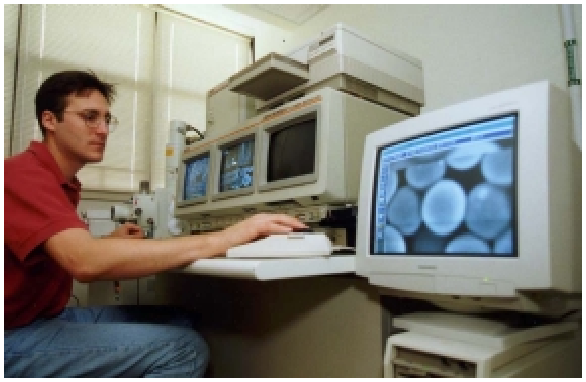

The Liquid Crystal Institute

65,000sqft, with 22,000sqft of research laboratories. 2,500 sqft $5M prototype facility; 2,000 sqft characterization facility; 2,000 sqft synthesis faciltiy

Tasks & Time Line

- Phase 1 Tasks
- Phase 2 Tasks
- Options
- The Time Line

Phase 1

- Phase 1 is an 18 month effort that will provide the research to quantify the best material and cell design approaches for a broadband OPA device. It will also consider the design approaches for a broad band de-centered lens steering system.
- Consists of Tasks 1-5

Task 1: **System Issues**

– Lockheed Martin Naval Electronics & Surveillance Systems-Akron (LM NE&SS-Akron) will provide consultation on the integration of components developed under this program by the KSU Team into an IRCM systems. Will provide target system specifications and insight into system operation to allow for optimum component designs.

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Task 2: **OPA Device Design**

– This central task is to determine the optimal approach toward having a device that switches 10 microns of phase retardation in 1 millisecond. This will be accomplished though modeling and device testing. Design of PDLC, polymer stabilized, Cholesteric, two-frequency, ECB, and multi-stage devices will be part of this task. Measurements will be done of the performance (transmission, switching time, required voltage) of test devices of the above and comparisons will be made with SmC* and interferimetric approach evaluations done elsewhere.

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Task 3: **OPA Materials Development**

- This will be the effort to test best candidate PDLC materials for speed and IR transmission. with the goal is 1 micron of phase retardation change in 1msec and very high transmission. Also included is IR transmission tests of SmC* materials for comparison data and transmission tests of straight nematic and materials that have a pitch short compared to the shortest wavelength of light for the application (2 microns) While we will not be doing new materials synthesis here, we will test custom synthesized per-deuterated materials. The result of the evaluations (through tests of accessible materials) will be the ability to predict that transmission (across the spectral region of interest) of materials (PDLC, SmC*, nematic, cholesteric) that could be developed in phase 2.

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Task 4: **IR OPA Cell Construction**

- Boulder Nonlinear Systems (BNS) to select the appropriate cell construction materials (substrate, AR coatings and conductive layers) for use in an OPA device to be used in the IRCM application. Will integrate work done a Handscom AFB on ZnO.
- Deliver cells with a 1cm active area.
- Build drive electronics and interconnects for the above cells.

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Task 5: **Modeling of Broadband Decentered Lens Devices**

– This task is to provide detailed understanding of the issues of using the de-centered lens approach to steering a broadband IRCM MWIR laser, and the focusing of a MWIR image from a distant point source onto a camera's CCD array. Of particular interest are the trade-offs in using a triplet of: single lenses , achromatic lenses, Fresnel lenses, array of macroscopic lenes, or a microlens array

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Phase 2

- An 18 month effort where the best OPA and decentered lens approach identified in phase 1 is, constructed, and integrated in to a unit that is testable for it speed, steering angles, and transmission in the MWIR. The result of the base program work in this phase will be provide data on the operation of the identified approach.

Task 6: **Phase 2 System Issues**

– LM NE&SS-Akron will provide consultation on the integration of a components developed under this program into an IRCM systems. We will provide target system specifications and insight into system operation to allow for optimum component designs.

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Task 7: **OPA Device Modeling and Optimization**

– The focus of this effort will be model in detail and test a broad band OPA device, using the approach defined in phase 1.

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Task 8: **OPA Materials Optimization**

– The LC material approach defined in phase 1 will be evaluated in more detail for use in MWIR OPA application.

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Task 9: **OPA Cell and Electronics Construction**

– Construct cells similar to those supplied in phase1.

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Task 10: **Decentered Lens Device Optimization**

– Design a de-centered lens steering device that is optimized for the IRCM application. The design methodology will be verified with test devices made to operate in the visible wavelength region. A clear path-way toward fabrication a device to operate in the 2 – 5 micron wavelength region will be provided, along with anticipated performance specifications.

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Option One

- The phase 1 effort will identify the best approach toward a broadband OPA device. The base level of phase 2 will allow more detailed evaluations of that approach. It is anticipated, however, that a successful component development effort will require research to provide improvements in the design, materials and electronics of the OPA device. This effort is included in an option to fund additional work during phase 2 .

- Specifically, this option will fund: Modeling and research for OPA design improvements related to task 7; Materials research related to task 8; and Cell and Electronics improvements related to task 9.

Option 2

- Phase 2+ will is a set of options will be available to contract administrator to enhance the above effort to be able to test and demonstrate a programmable unit that can steer a MWIR laser. Specifically it wil fund: Use of LM NE&SS-Akron’s MWIR test station for component tests; a 2nd axis OPA device and programmable electronics; and a 1” diameter MWIR programmable decentered lens demo unit.

The Time Line

			Q1-Q2	Q3-Q4	Q5-Q6	Q7-Q8	Q9-Q10	Q11-Q12
Phase1 Evaluation	Task 1	LMTDS		System Issues				
	Task 2	KSU	Design Comparisons					
				PDLC & Ch limits				
	Task 3	KSU	OPA Materials					
	Task 4	BNS		OpticalHeadConst				
	Task 5	UD		Decent Lens Model				
Phase 2 Base effort	Task 6	LMTDS				System Issues		
	Task 7	KSU				Design Testing		
						Design Mods		
	Task 8	KSU				Materials Supply		
	Task 9	BNS				Additional Cells		
	Task 10	UD				Decent Lens Opt.		
Option 1 anticipated additions	Task 6	LMTDS						
	Task 7	KSU				Design Improvements		
						Design Opt.		
	Task 8	KSU				Materials Resh.		
	Task 9	BNS				Improvements		
	Task 10	UD						
Option 2 Demo additions	Task 6	LMTDS					Comp. Tests.	
	Task 7	KSU						
	Task 8	KSU						
	Task 9	BNS				2ndHead, ProgElec,		
	Task 10	KSU /UD					demo	