Liquid Crystal-based Beam Steering Technologies for NASA Applications

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Liquid crystal-based beam steering devices can provide electronic beam scanning to angles above 1 milliradian, sub-microradian beam pointing accuracy, as well as wave-front correction to maintain output optical beam quality. The liquid crystal technology effort will be summarized, and the potential application of the resulting devices to NASA space-based scenarios will be described.

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Vision for Space Exploration

- Retire Space Shuttle (2010)
- Build Crew Exploration Vehicle (2014)
- Build Crew Launch Vehicle and Heavy Lift Launch Vehicle (2014)
- Complete International Space Station (2010)
- Extend human expeditions to Moon (2018)
- Explore Solar System and beyond (> 2030)

Background Information:

NASA Research Announcement issued in CY 1999

Thrust Area: high rate data delivery

- Precise optical beam pointing (suppressing of the effects of spacecraft platform vibrations)
  -- submicroradian steering accuracy
  -- several milliradians of overall steering range

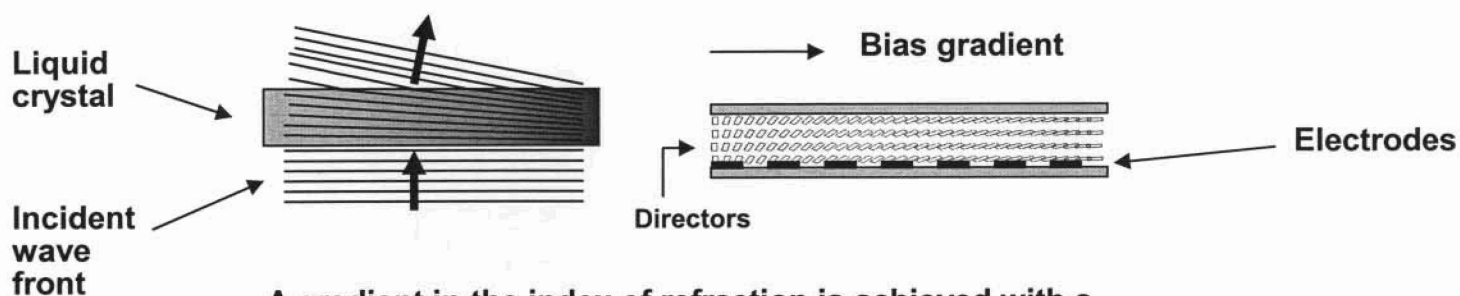
- High accuracy (near diffraction limited), low cost, and thermally stable optical telescopes

Benefits of Optical Communications:

- Higher gains and higher data rates
- Potential for low mass (low-weight payloads), small size (receivers/ transmitters), and low power consumption
- High bandwidth (> 1 GHz)
- Narrow beams (communications security)

Purpose of this Effort:

The project is focused on non-mechanical, low-cost, light-weight, low-power beam steering with wave-front control.



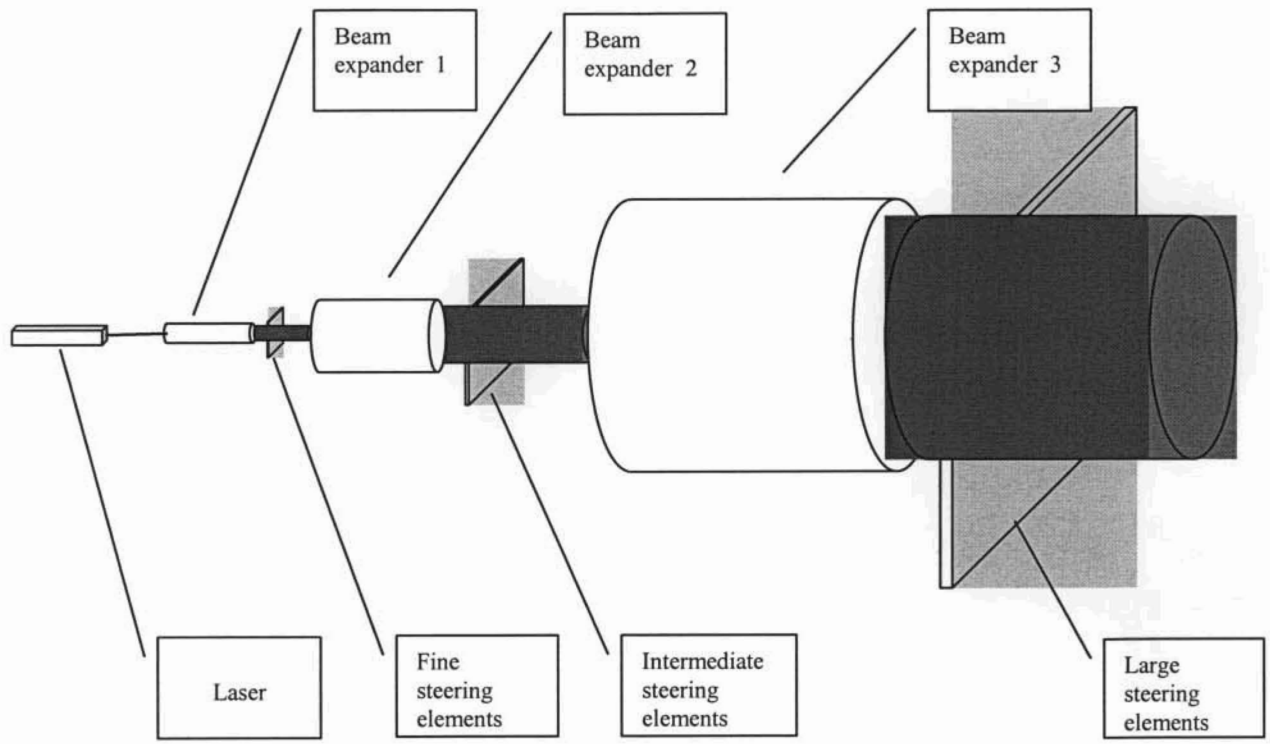
A gradient in the index of refraction is achieved with a liquid crystal device (source: Liquid Crystal Institute, Kent State University, Kent, OH).

Liquid Crystal-based Beam Steering Concept

- Optical phased array (OPA) provides fine steering.
  Range: 0.1 – 100 μrad

- Digital beam deflector provides intermediate steering.
  Range: 0.1 – 1 mrad

- Large angle pointing subsystem.
  Range: > 100 mrad



Source: LCI/KSU

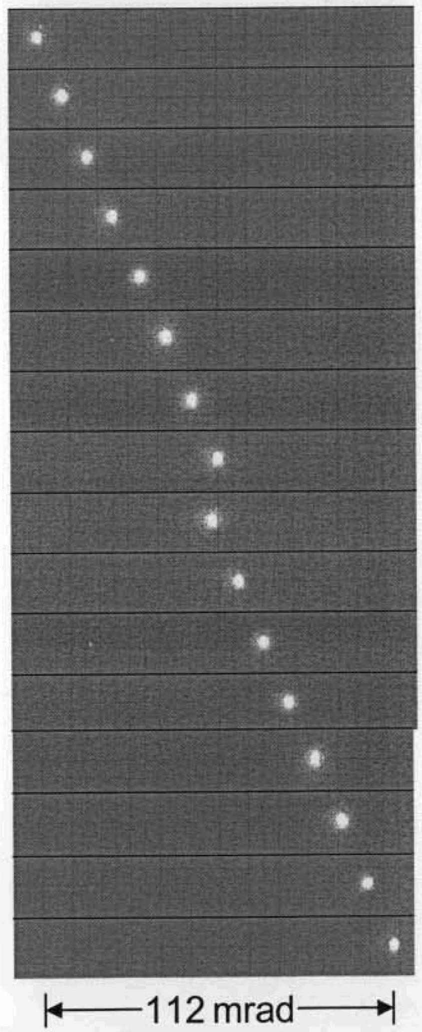
Operational Characteristics:

- Design for 1.5-micron wavelength operation
- Testing at helium-neon wavelength (0.6328 micron)
- Electronic (non-mechanical) beam steering
- Beam steering ~ milliradians
- Beam pointing accuracy ~ submicroradian
- Wave-front correction capability
- Low weight, low cost, low power consumption
- Use of commercial, off-the-shelf parts, e.g., liquid crystal on silicon (LCOS) components

Operational Characteristics (continued):

- High output efficiency (89% or better) measured for device
- Accurate steering: to (1/10) x beam divergence
- An 8-inch parabolic reflector with distortions was corrected
  -- Before correction: 34 wavelengths of aberration peak-to-valley at 0.6328 micron
  -- After correction: (1/10) wavelength of aberration peak-to-valley

Positions of laser beam steered by digital beam deflector.



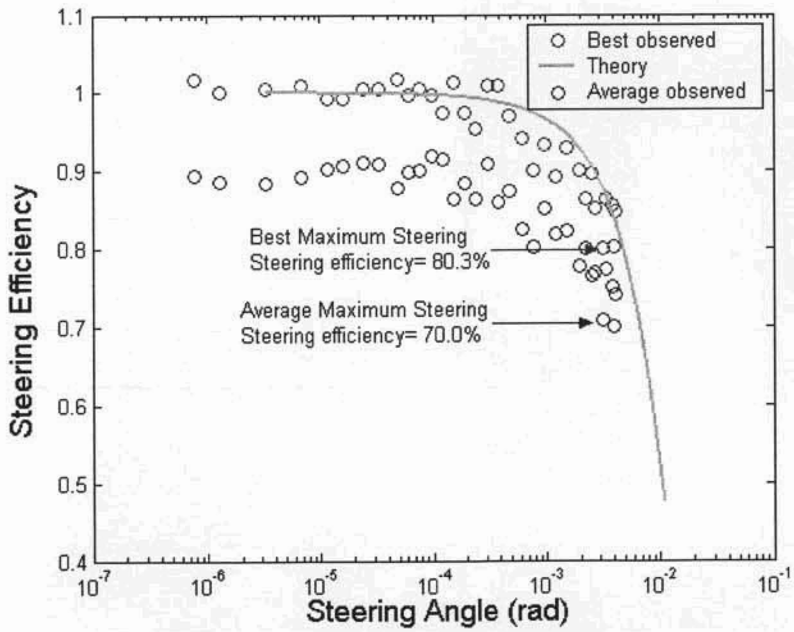
Demonstration of laser beam steering using a liquid crystal-based digital beam deflector. Range along x-axis: ± 56 mrad; step size: 8 mrad (source: LCI/KSU).

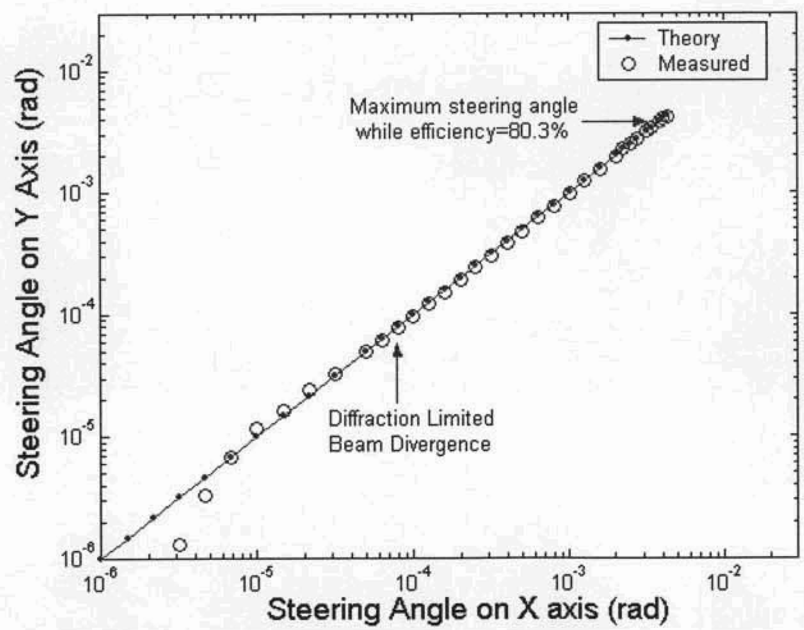
Two-dimensional LCOS OPA steering efficiency and accuracy.

Steering range: **4 mrad (± 0.23°) along x- and y-axes**

Steering accuracy: 10 μrad (1/10 diffraction limited beam divergence)

Steering efficiency: > 80%





Source: LCI/KSU

Wave-front aberration introduced by the primary mirror of an 8-inch telescope.

Before correction:

34 wavelengths of aberration peak-to-valley

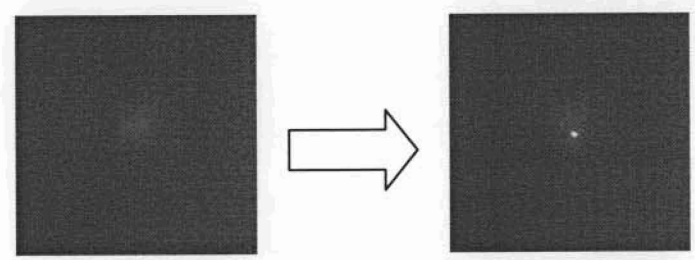
Strehl ratio = 0.006

After correction:

1/10 wavelength of aberration peak-to-valley

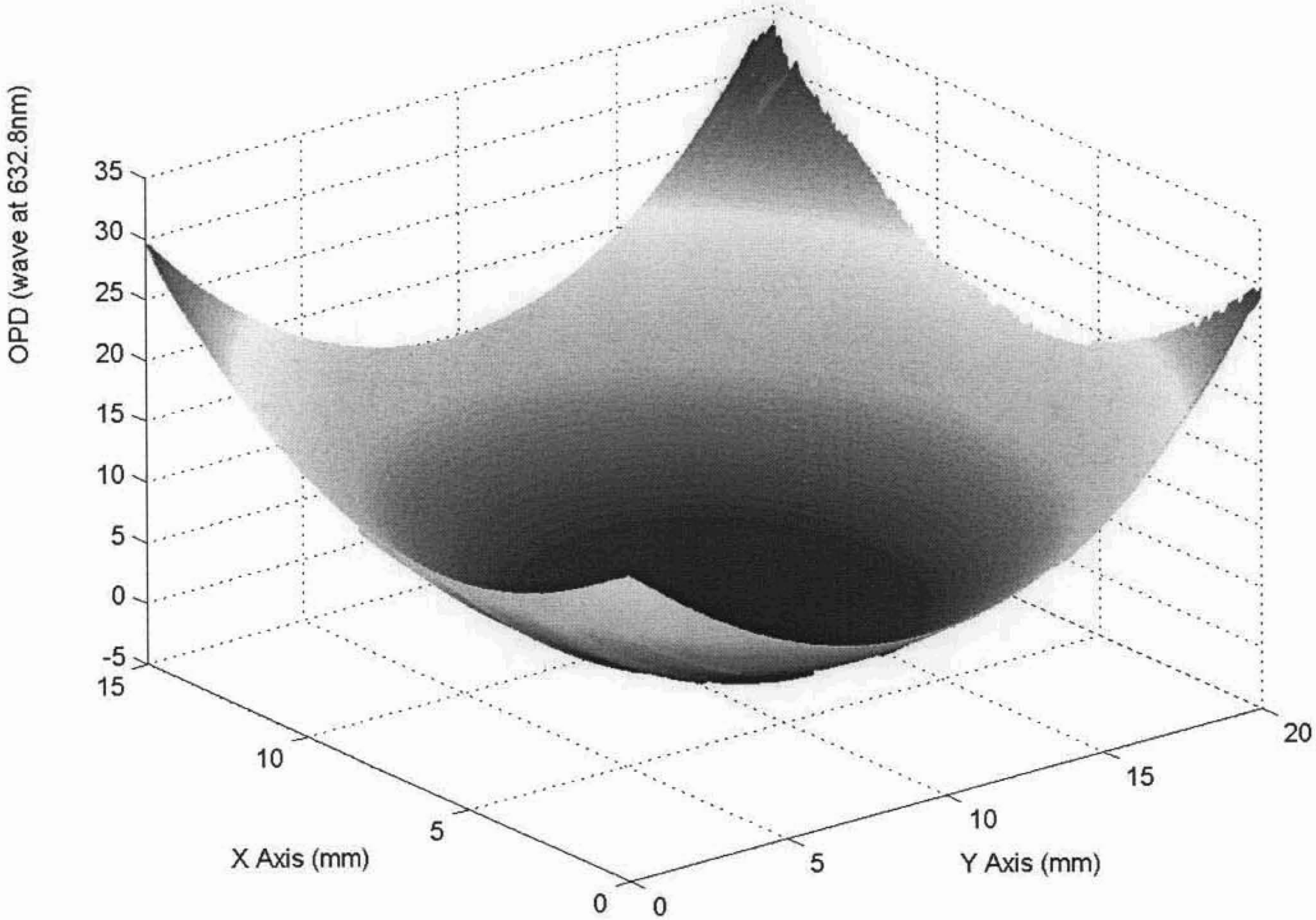
Strehl ratio = 0.83

Diffraction limit attained



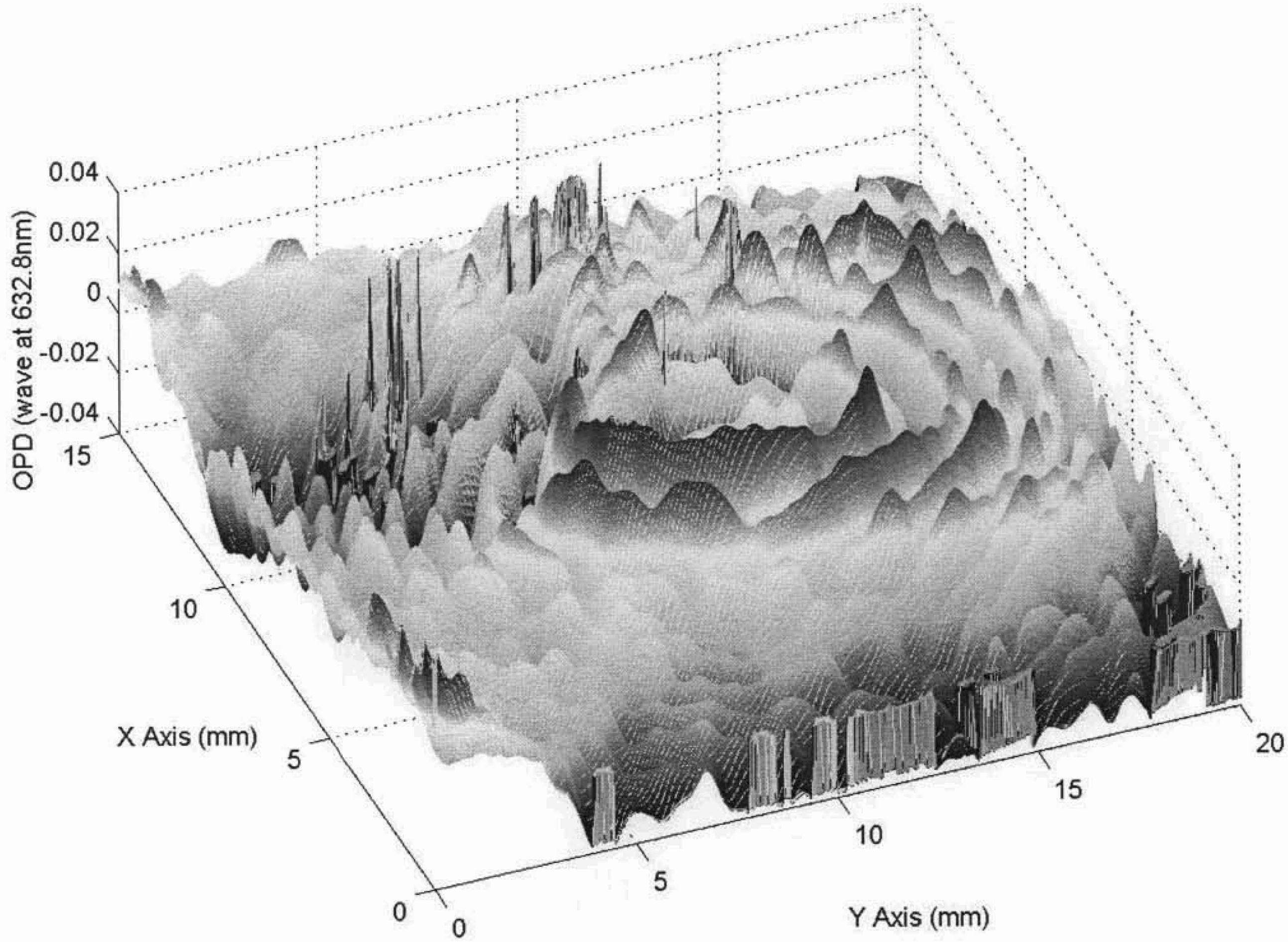
Laser beam prior to correction (left), and after correction (right). Source: LCI/KSU.

Distribution of optical path difference (OPD) prior to wave-front correction.



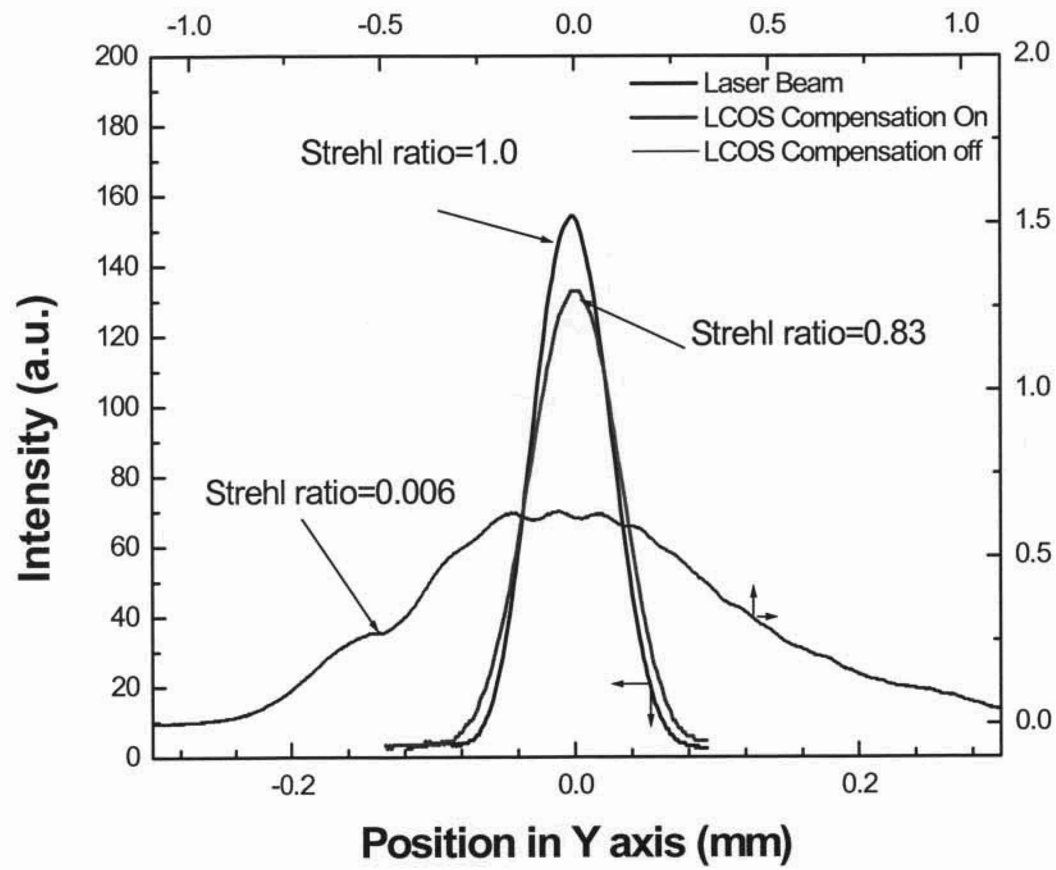
Source: LCI/KSU

Distribution of optical path difference after wave-front correction.



Source: LCI/KSU

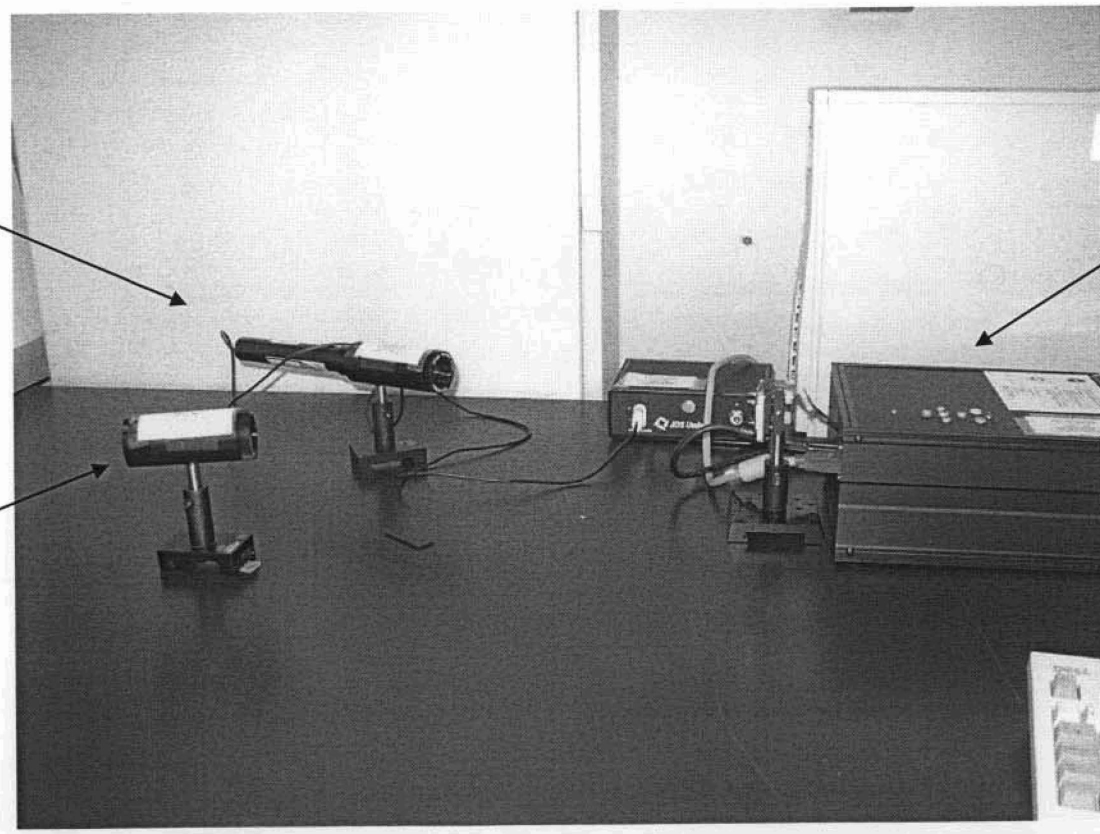
Beam intensity in the far field for different Strehl ratios.



Source: LCI/KSU

Optical beam steering device at the NASA Glenn Research Center, Cleveland, OH.

Module contains laser source, polarizer, and beam expander



Module for LCOS wave-front corrector and control electronics

Beam expander

Source: LCI/KSU

Accomplishments:

- Optical beam steering device delivered to NASA GRC
- Theoretical models (finite-difference time domain) developed
- Demonstrated wave-front correction, target tracking, beam shaping, and beam splitting into two and four beams (independent movement)
- NASA technology readiness level (TRL) 3

Potential Applications:

- Submicroradian beam pointing technology. Scanning range ~ milliradians; in situ wave-front correction; low cost, compact design, low weight, low power consumption
- OPA systems (surface wireless communications)
- Precision tracking of robotic systems, landers, spacecraft, habitats, and astronauts
- Optical communications systems/networks
- In situ resource utilization (life support systems, fuel)
- Low-cost elements for arrayed, large-aperture, optical telescopes (deployed on the Moon)
- Science data acquisition

Summary:

- Precision beam steering supported using low-weight, small-size, low-power components; higher data rates via optical technologies; diffraction limited; wave-front correction

- Insertion opportunities for tracking/communications (test beds) in support of the Vision for Space Exploration

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