New Concepts for Inspecting Aspherical Optics

Presented at

7th Annual Mirror Technology Days in the Government

by

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www.metrolaserinc.com

Presented by David Content, NASA GSFC

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Hotel Albuquerque

Albuquerque, NM USA

Project Objective

- Determine the feasibility of a combined, Hartmann/Digital Holographic interferometry inspection system employing a dynamic holographic optical element.
  - Wide dynamic range for inspecting advanced optical components, including aspheric optics.
  - Complementary measurements with fractional wavelength resolution
  - Measurements with little or no wavefront stitching.

Key Interests of NASA GSFC

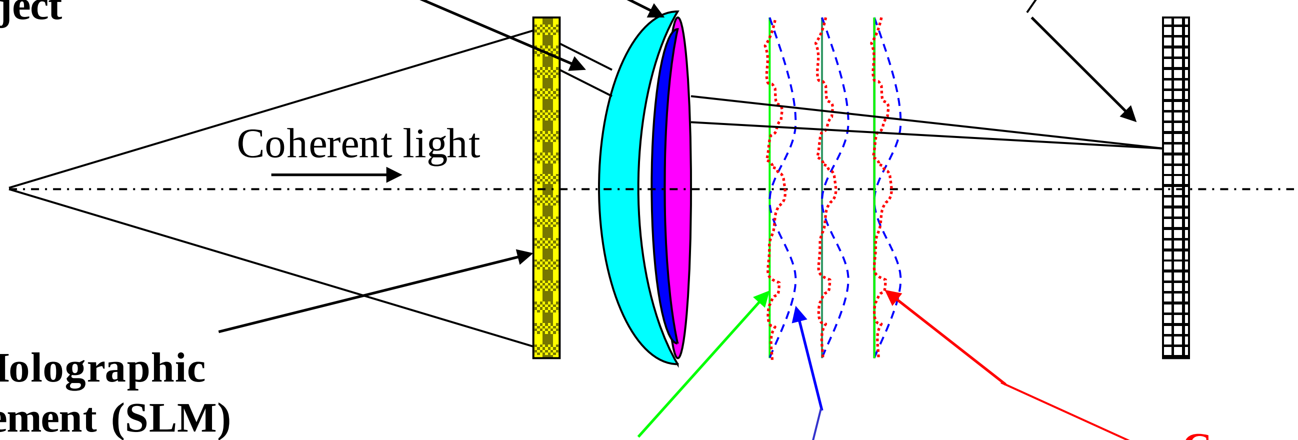
- Primarily reflective optics but also some transmissive
- Mostly visible but some IR
- 100-500mm, larger on rare occasions
- Optics not handled by conventional interferometry
  - Off-axis
  - Conics
  - Aspherics
  - Toroidal
  - Grating blanks

The Concept

Optics under test

Compensated light pencil for Hartmann sensing and scanning over test object

CCD records interferogram and Hartmann focus point



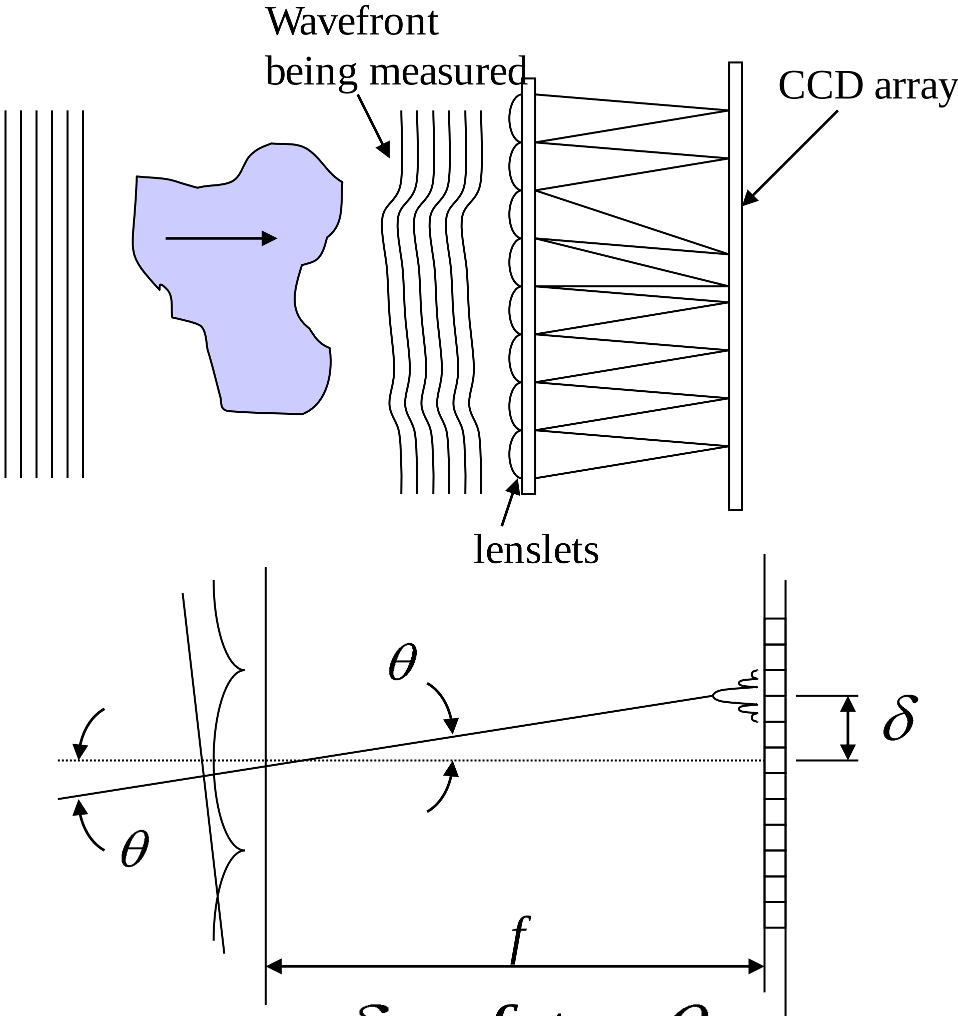
Dynamic Holographic Optical Element (SLM) programmed to produce and scan Compensated waves for perfect component

Compensated wave for perfect component

Uncompensated wave for perfect component

Compensated wave for imperfect component, i.e. difference between perfect and imperfect

Shack-Hartmann Characteristics



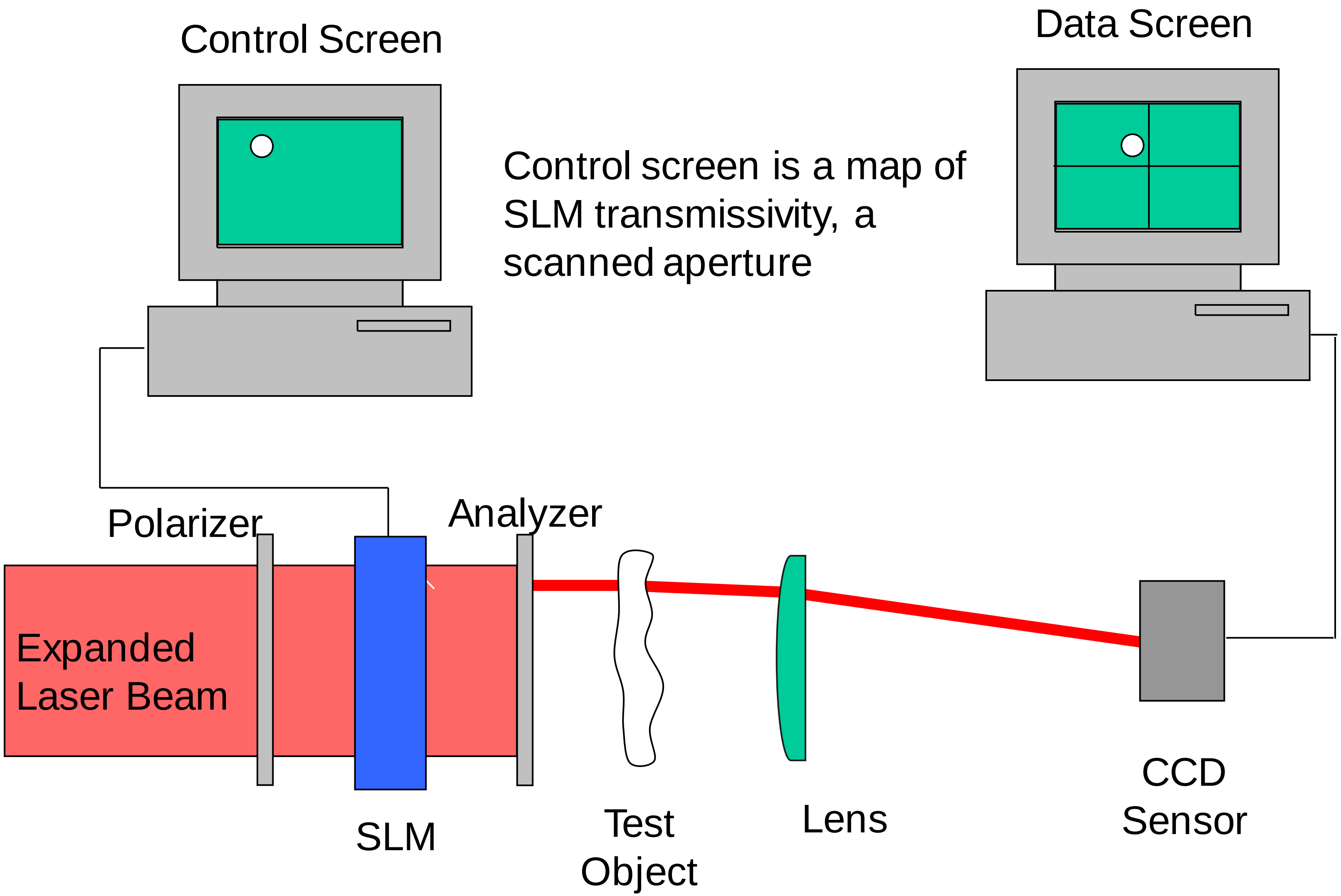
$$\delta = f \tan\theta$$

- Lenslet diameters, d, define spatial resolution over the wavefront being measured.
- δ (sensitivity) proportional to *f*, and should be less than d to prevent confusion

Constraints in conventional Hartmann Testing that can be obviated with this concept

- Sensitivity requires a longer focal length which can cause focused image overlap of adjacent light pencils.
- If the wave is aberrated, the focused spot will not be round, so its centroid is more difficult to locate, further reducing accuracy
- Spatial resolution is limited to the diameter of the lenses in the array.

Scanning Shack-Hartmann System



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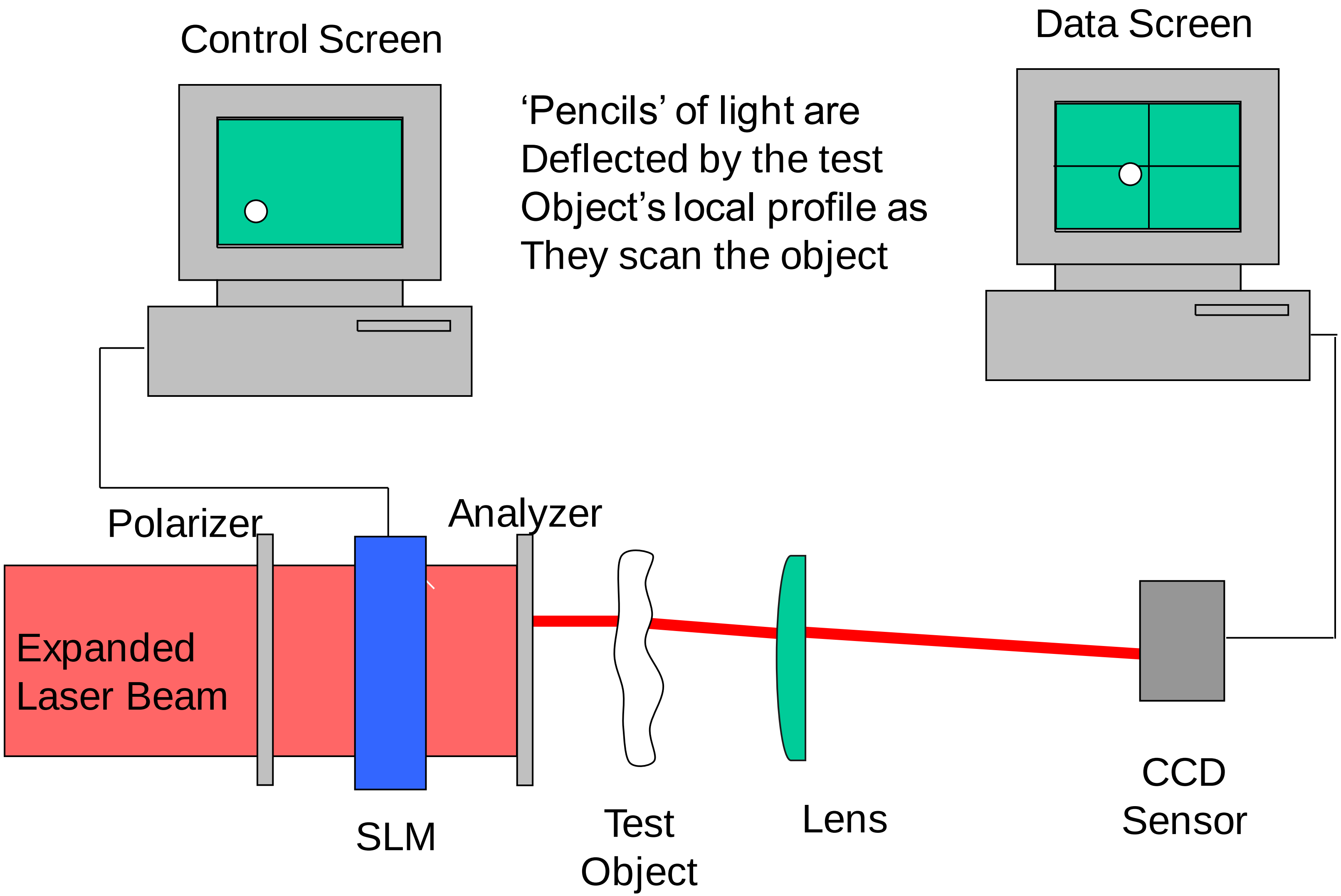
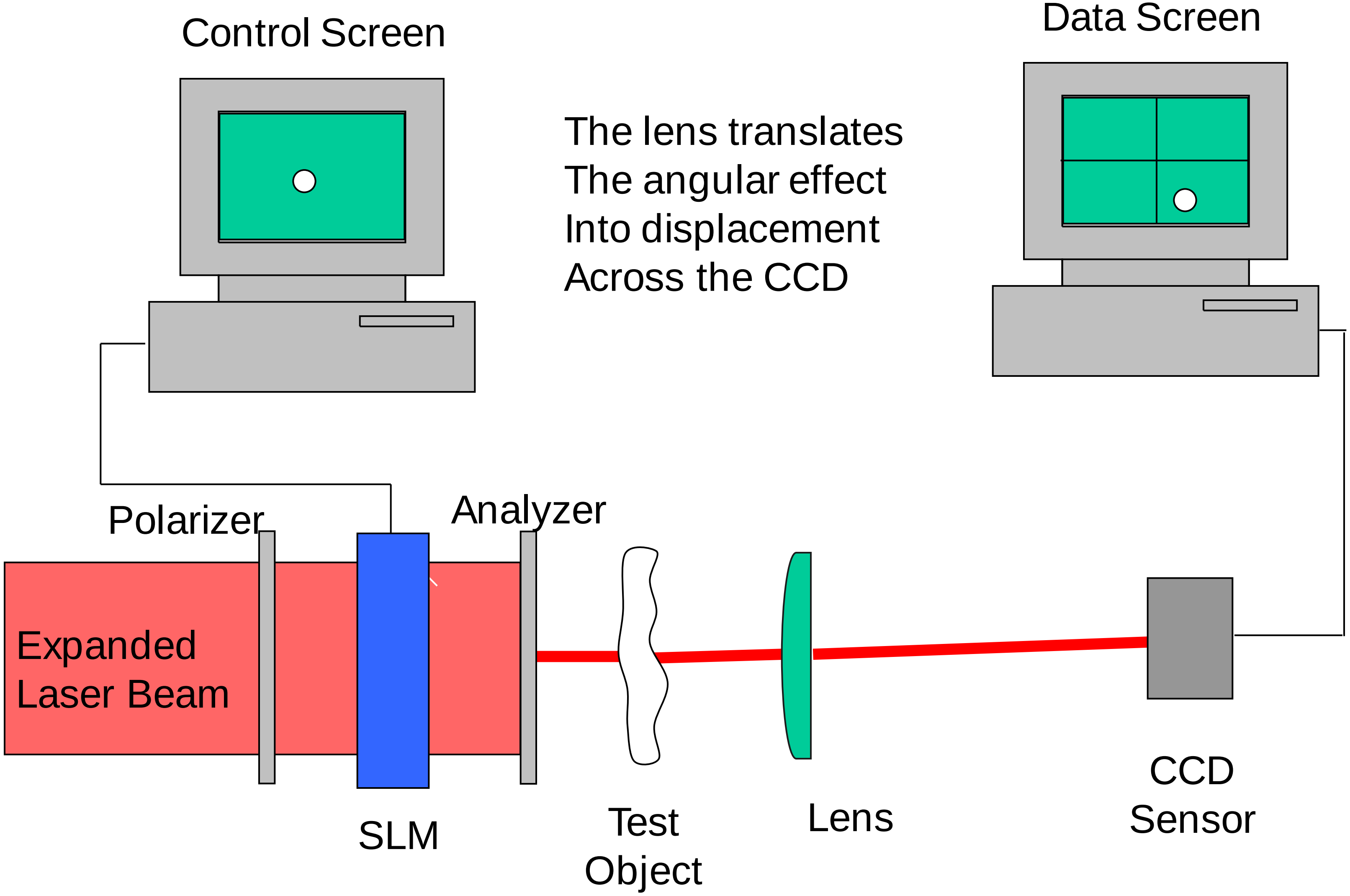
Scanning Shack-Hartmann System



Scanning Shack-Hartmann System

The lens translates
The angular effect
Into displacement
Across the CCD



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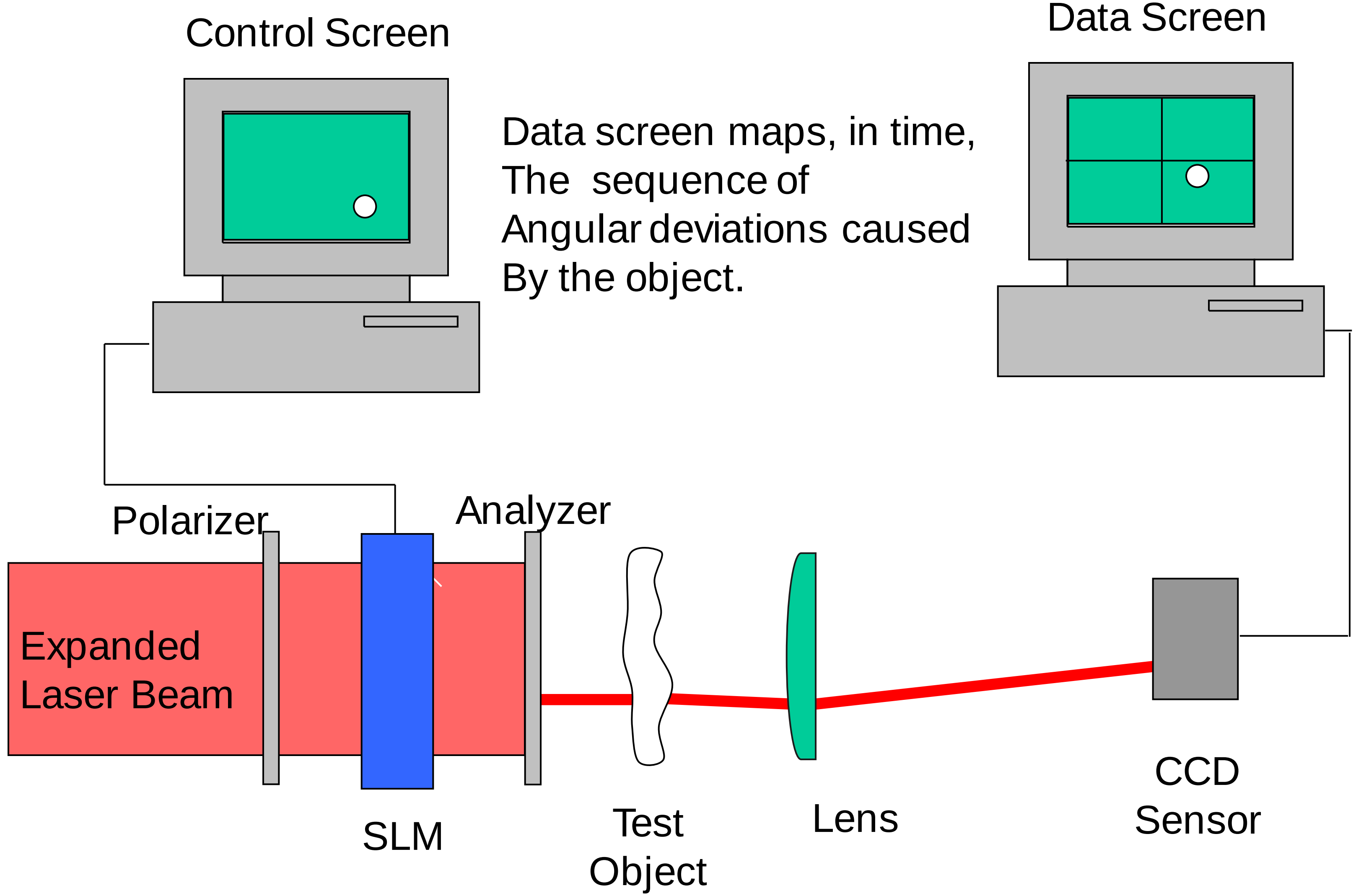
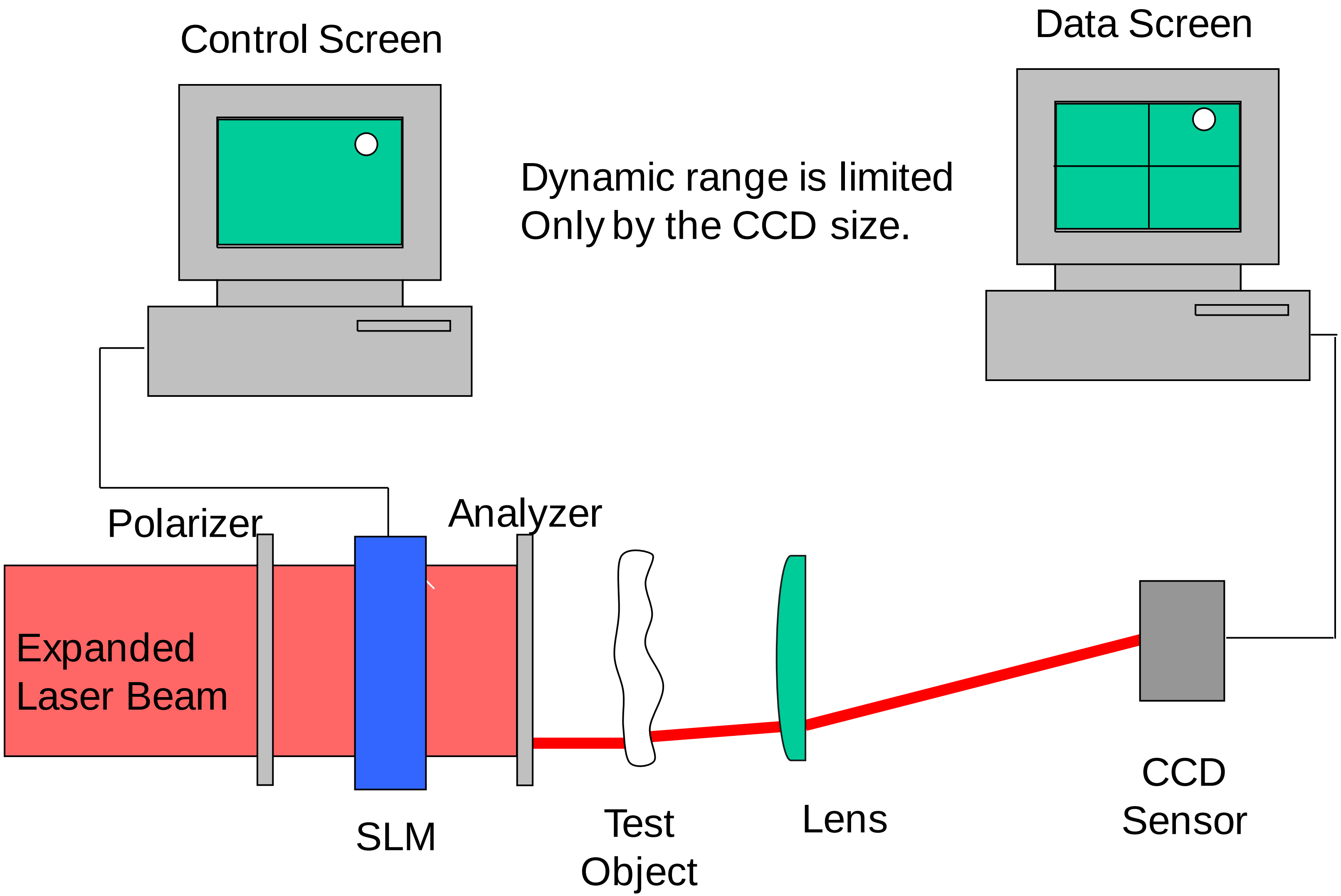
Scanning Shack-Hartmann System

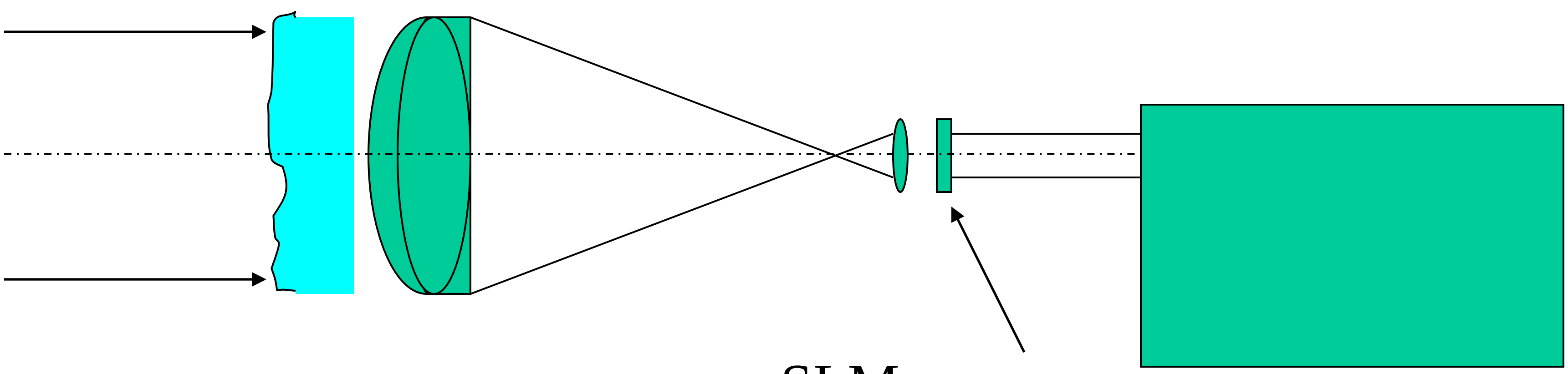
Data screen maps, in time,
The sequence of
Angular deviations caused
By the object.



Scanning Shack-Hartmann System



Testing Large Non Focusing Optics



Freeform Optics under test

Collimating lens

SLM (Dynamic Holographic Optical Element)

PhaseCam Or Hartmann System

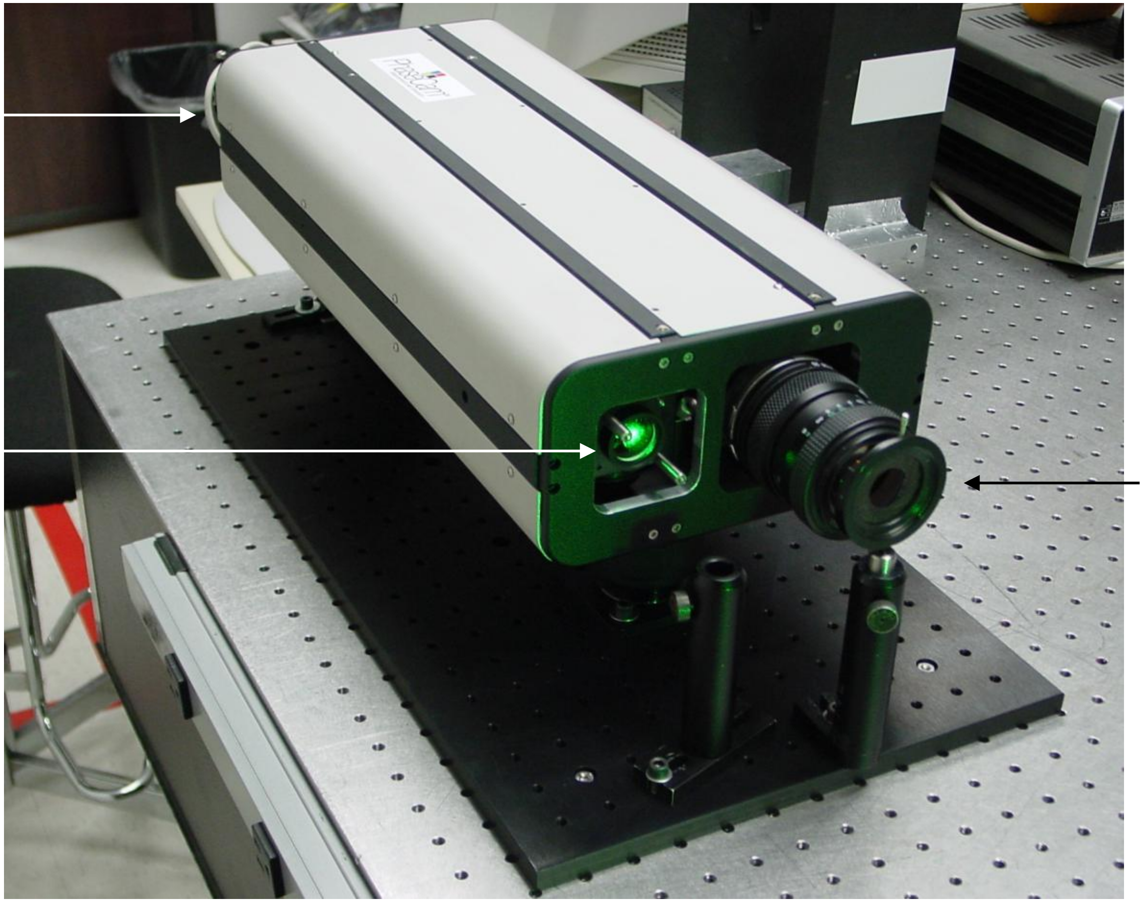
Electronic (Digital) Holography

- Holographic data stored on CCD array.
- Digital wavefront reconstruction
  - ❖ **Phase shifting interferometry (hologram plane).**
  - ❖ **Diffraction theory (propagate to image).**
- Interferograms are computed.
- Amenable to fiber optical implementation.

*Commercial MetroLaser wavefront sensor**

Laser

Object Beam
Transmitting Lens



Receiving Lens

*Produced by 4D Technologies, Incorporated, Tucson Arizona

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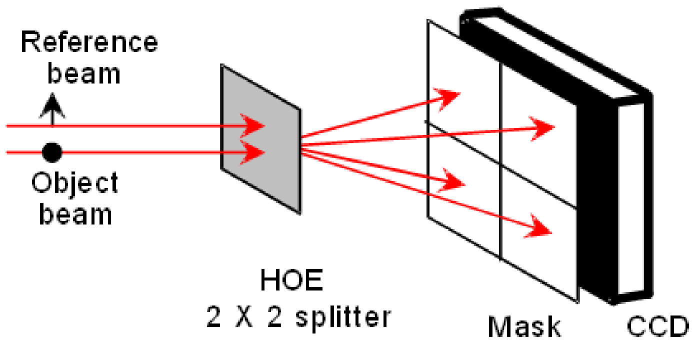
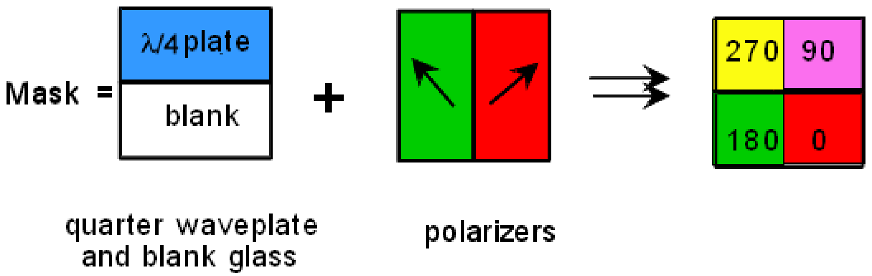
Phase Shifting Interferometry

$$\Delta\phi(x,y) = \arctan\left(\frac{I_3(x,y) - I_1(x,y)}{I_0(x,y) - I_2(x,y)}\right)$$

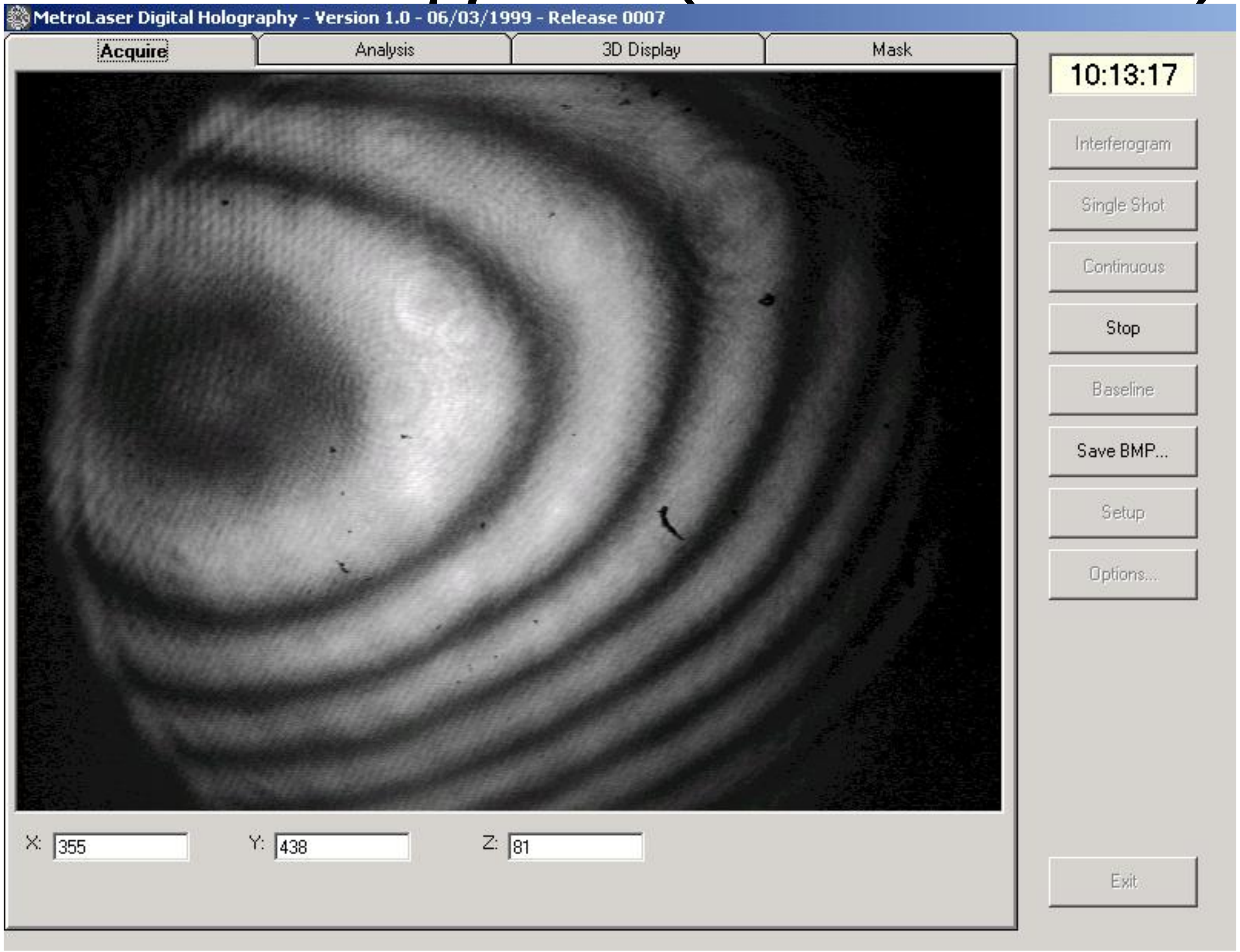
$$\tan(a-b) = \frac{\tan a - \tan b}{1 + \tan a \tan b}$$

$$\Delta\phi(x,y) = \arctan\left(\frac{\sum_{p,q\in\delta} X(p,q)}{\sum_{p,q\in\delta} Y(p,q)}\right)$$

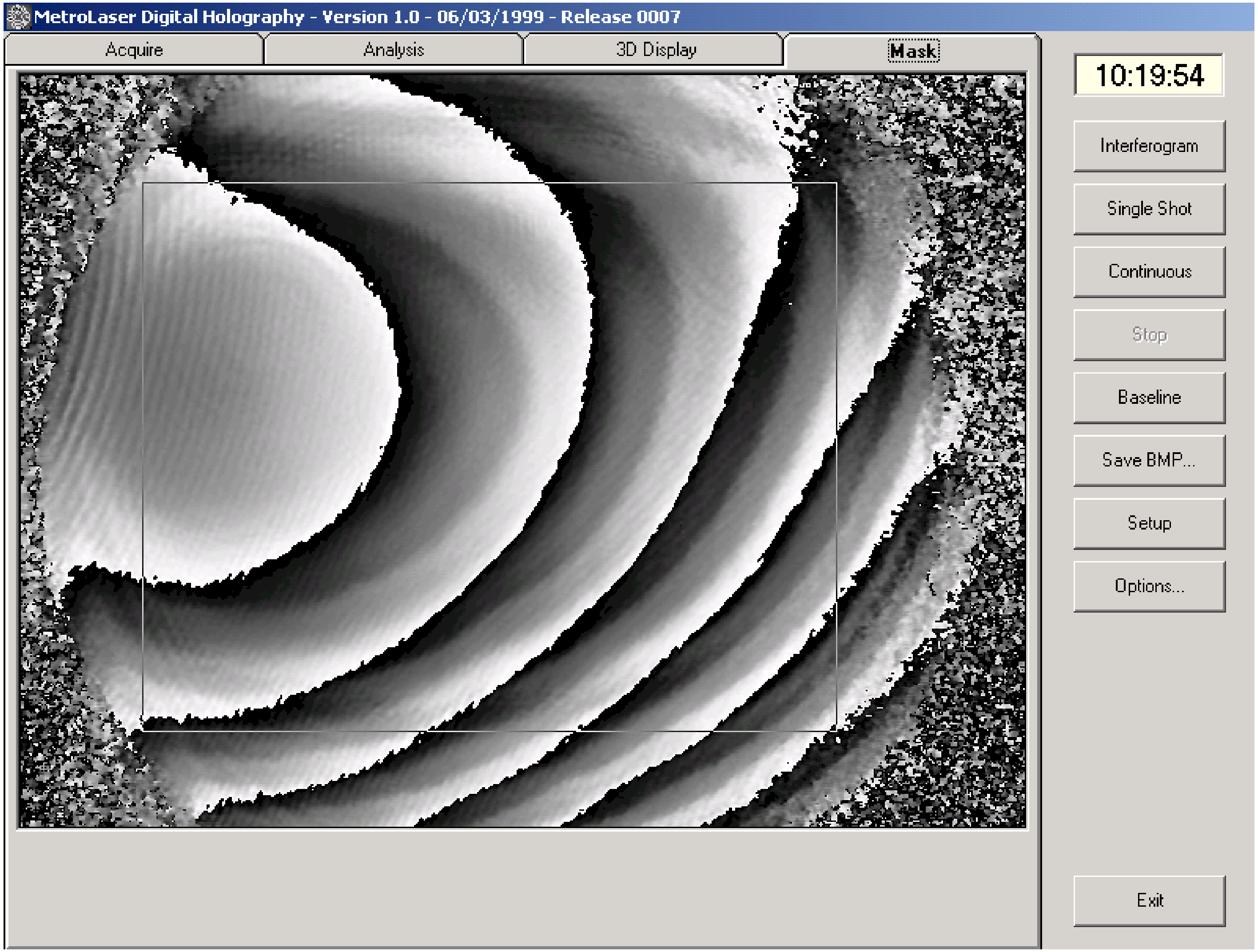




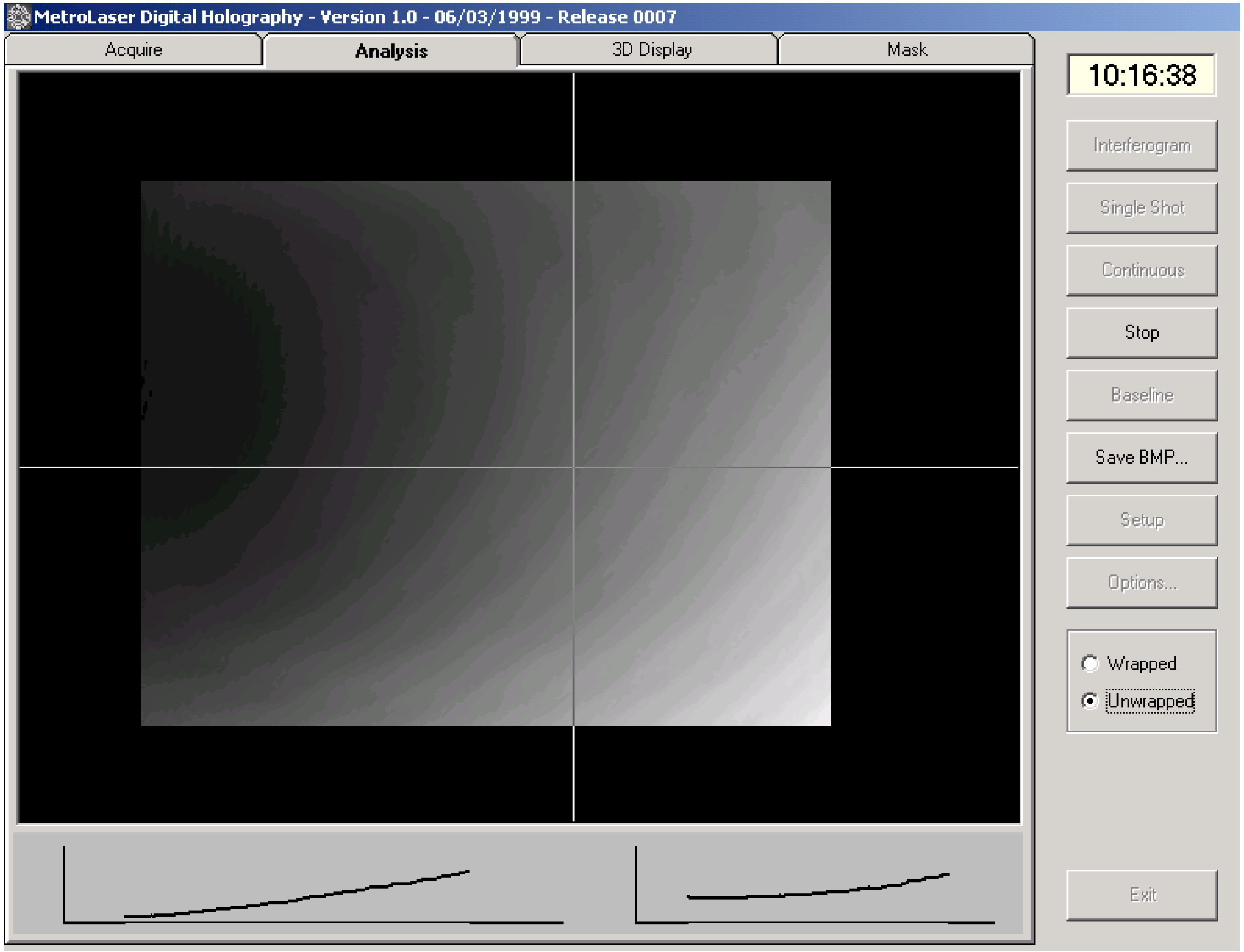
Interferogram (one of four)



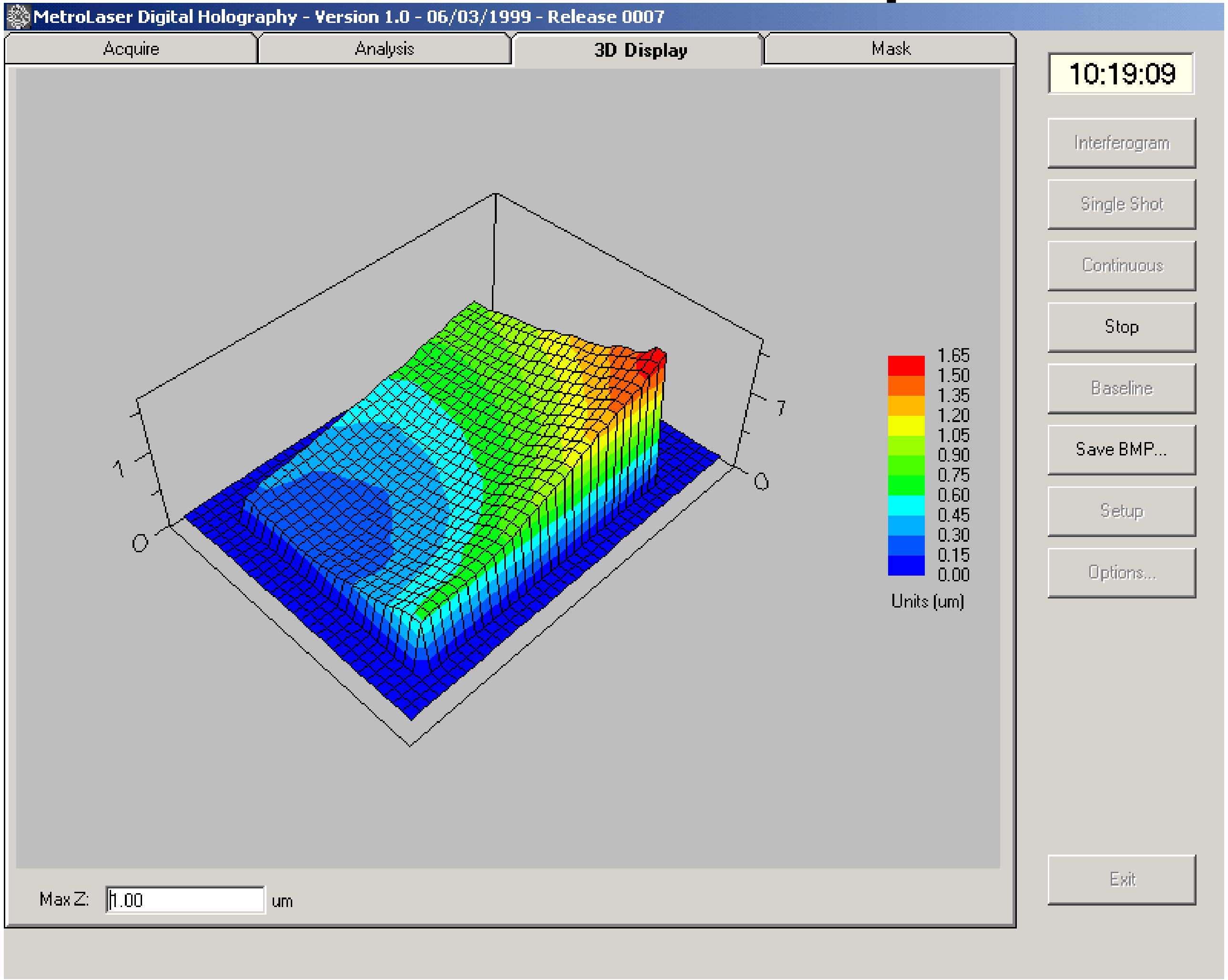
Wrapped Phase Map of a Test Plate



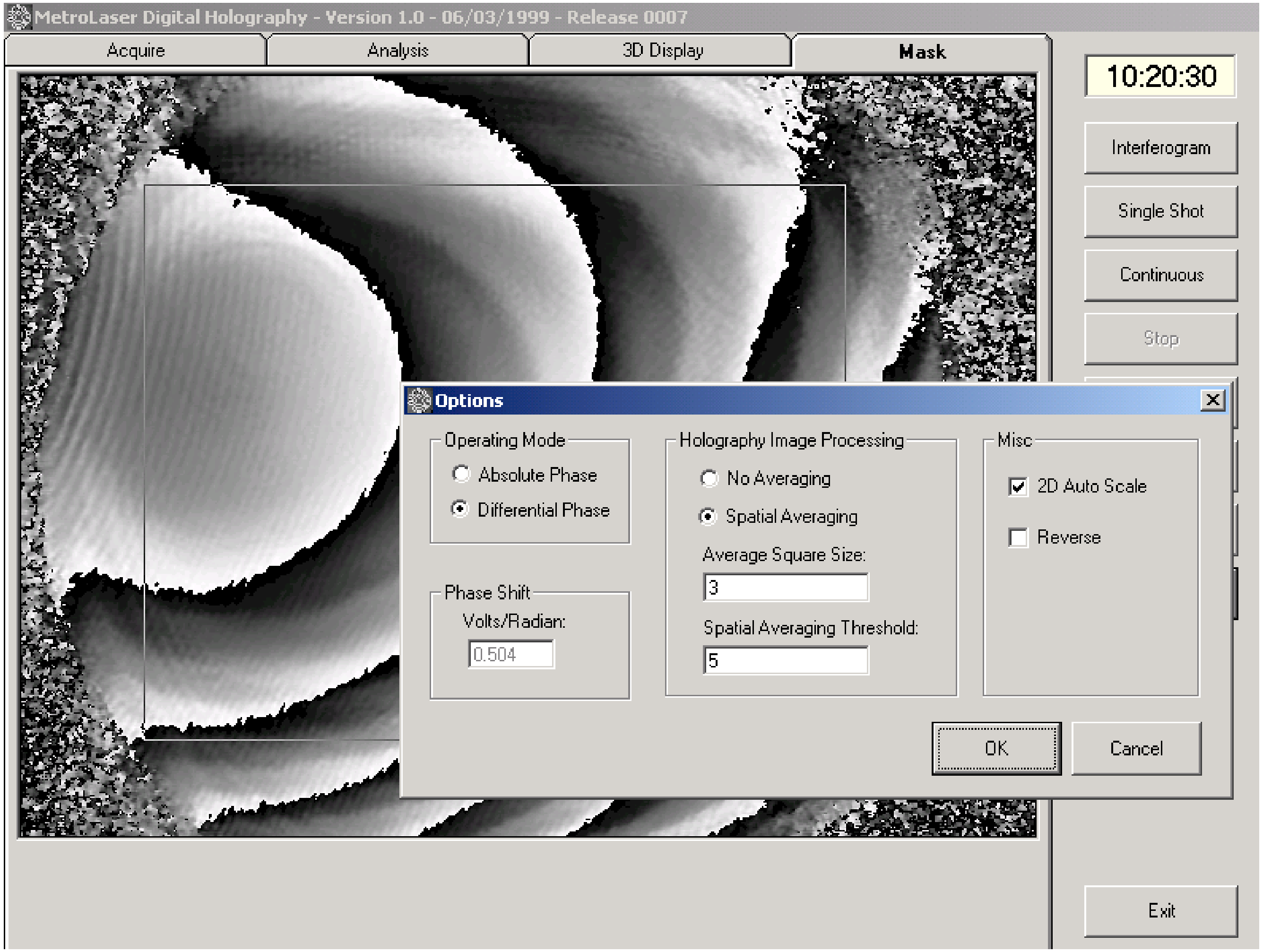
Unwrapped Phasemap



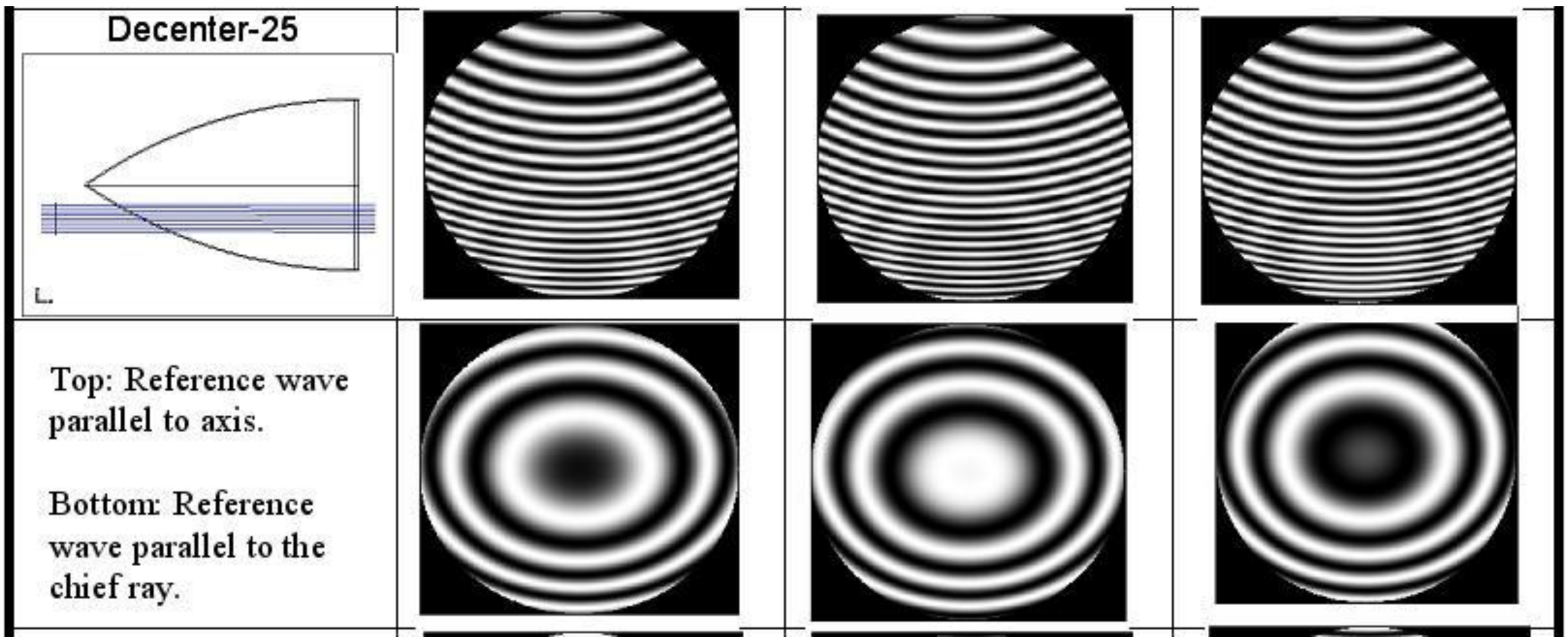
Phase Map


MetroLaser Digital Holography - Version 1.0 - 06/03/1999 - Release 0007
Acquire
Analysis
3D Display
Mask
10:19:09
Interferogram
Single Shot
Continuous
Stop
Baseline
Save BMP...
Setup
Options...
Exit
1.65
1.50
1.35
1.20
1.05
0.90
0.75
0.60
0.45
0.30
0.15
0.00
Units (um)
Max Z:
1.00
um

Modes of Analysis



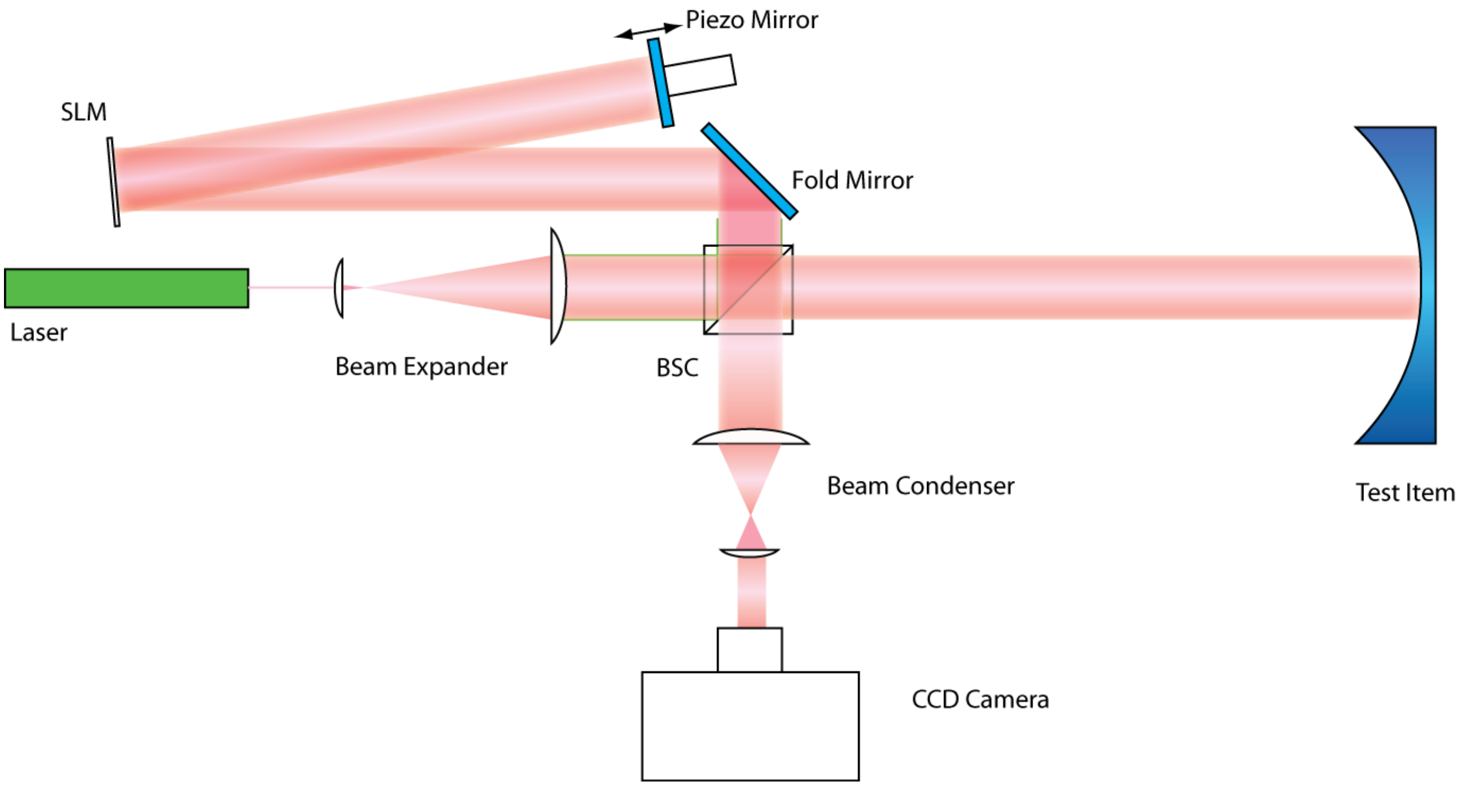
Increasing dynamic range by adjusting the reference wave



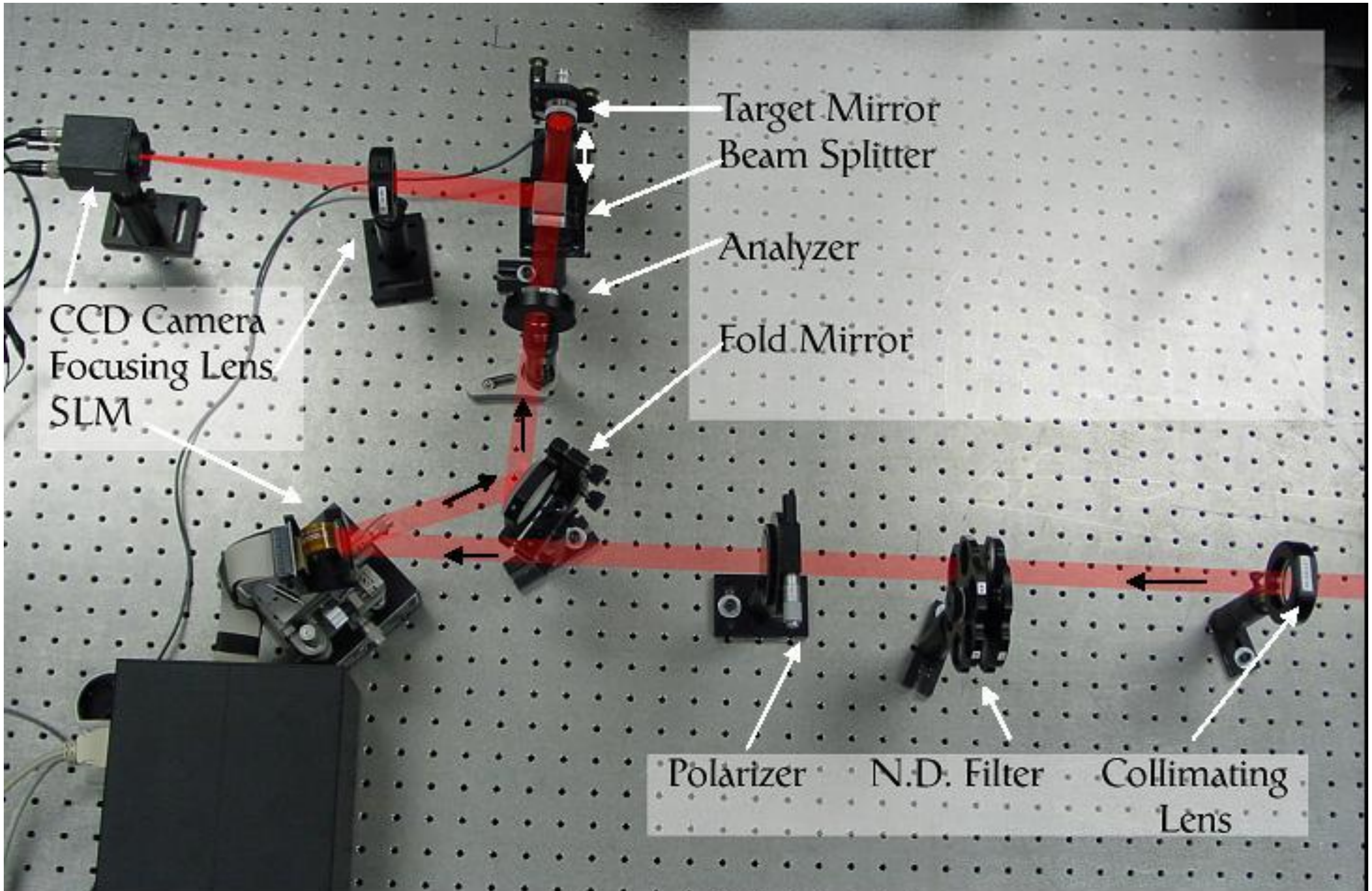
Some Critical Questions Answered

- Can preconditioning the wavefront for either Hartmann sensing or extended range interferometry extend the area of coverage in a practical and useful way eliminating stitching?
- How well will a dynamic, computer generated hologram (DCGH), perform the function of wavefront conditioning?

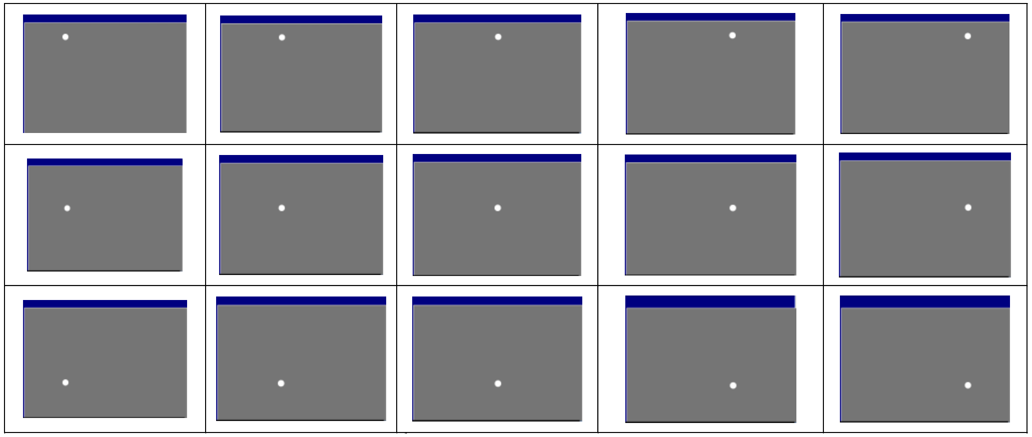
Demonstration Breadboard



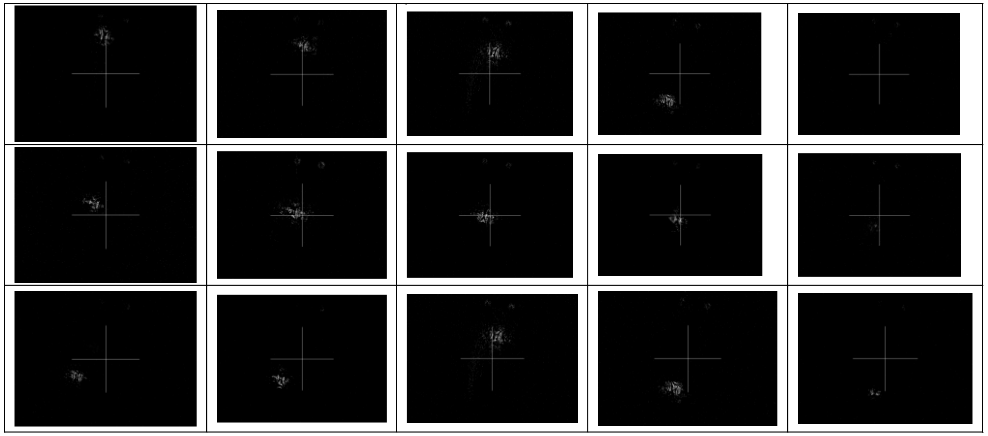
Demonstration Breadboard



Shack-Hartmann scanning a freeform optical component

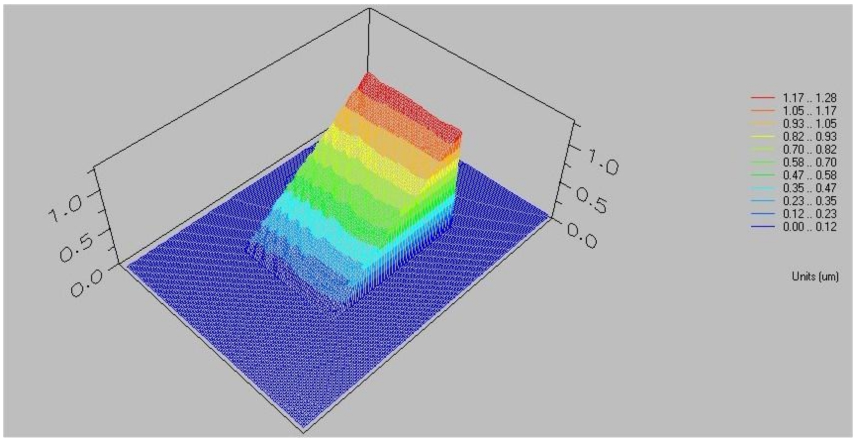


SLM transmissivity

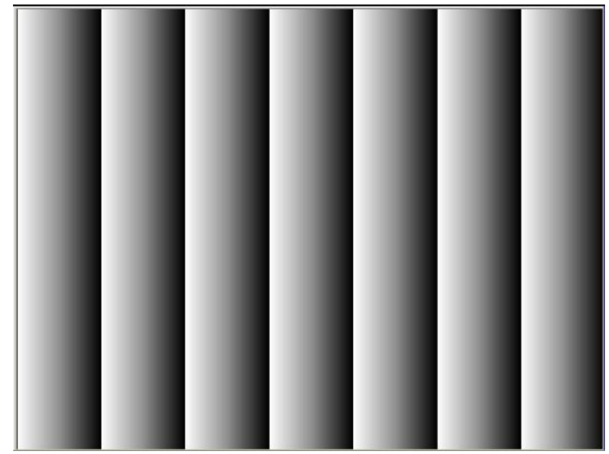


Wavefront data

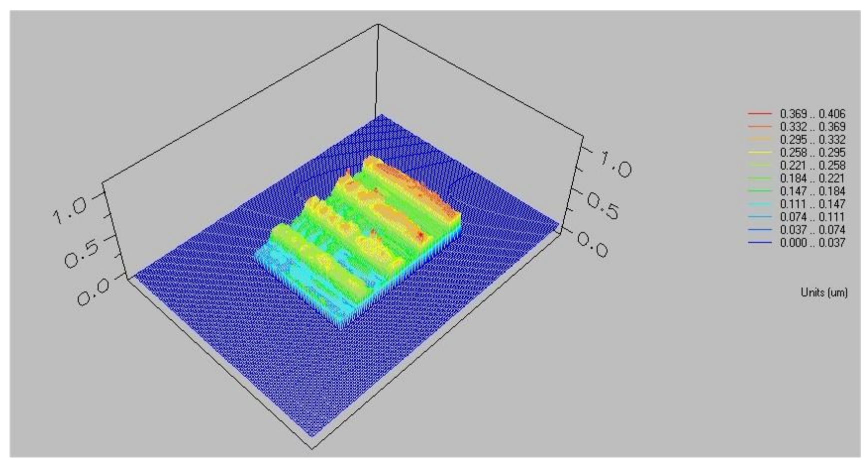
Removing wavefront tilt with the SLM



Tilt added to a wavefront

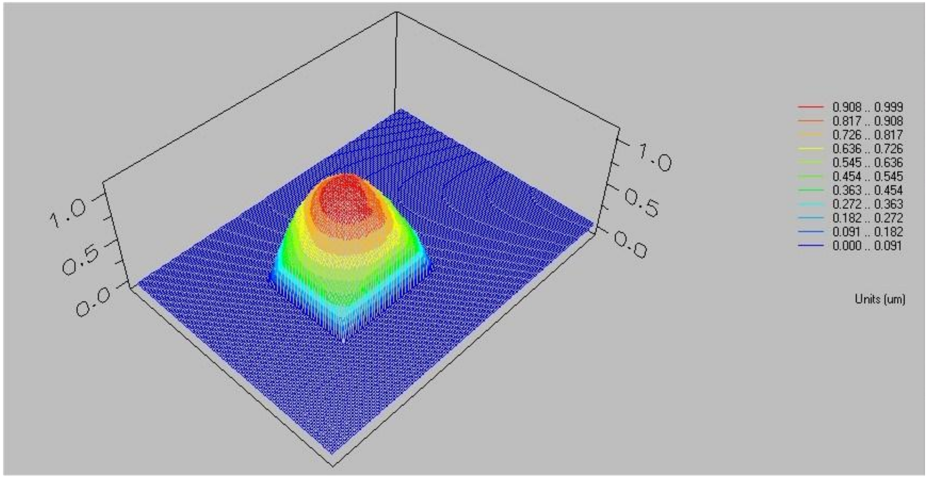


Tilt programmed on the SLM

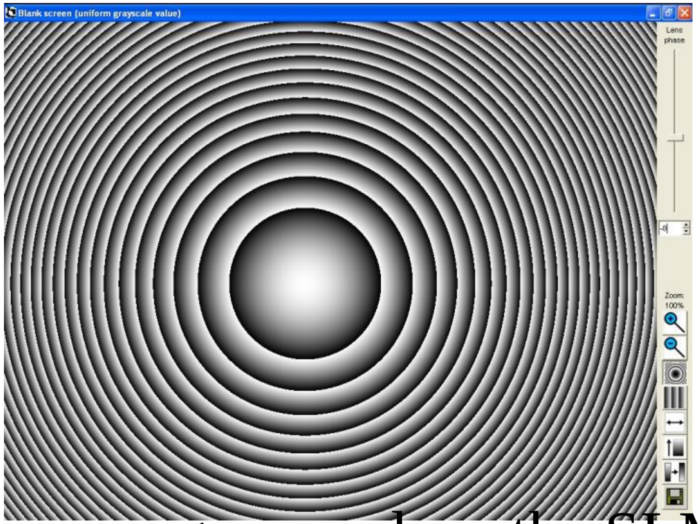


PhaseCam analysis after tilt removal. (Residual fringes due to non linear SLM response.)

Removing Wavefront Sphere with the SLM

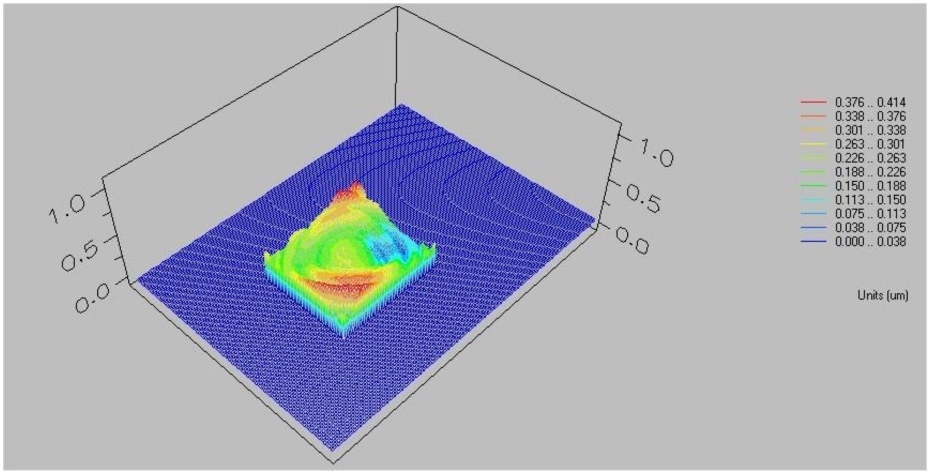


Sphere added to a wavefront



Sphere programmed on the SLM

PhaseCam analysis after sphere removal. (Residual fringes due to non linear SLM response.)



Key Features and Benefits

- A unique combination enables integrating two powerful, null point, inspection techniques, Hartmann and digital holographic interferometry by using a dynamic holographic optical element.
- Removes existing limitations of Hartman and interferometry.
- Preconditions test wavefront for specific test article, by being programmed to compensate for predicted distortion of a perfectly manufactured part.
- Interferogram recorded and computed by digital holography measures difference between perfect and imperfect optic.
- Electronically Scanned Hartmann sensor measures difference between perfect and imperfect optics focus positions.
- SLM can provide wavefronts of arbitrary shape for testing the measurement system itself, avoiding the problem of unavailability of test items on which to assess the applicability of the inspection system.

Conclusions

1. COTS SLM's are adequate to employ as dynamic HOEs for this concept.
2. They require considerable characterization and modification for this application.
3. Many waves of tilt and curvature can be compensated by wavefront preconditioning.
4. Many limitations of Hartmann testing can be eliminated.
5. A combined digital holographic interferometer and an SLM can provide complementary measurements and an unlimited dynamic range.

MetroLaser
Irvine, California

NASA SBIR/STTR Technologies

SBIR STTR

An Instrument for Inspecting Aspheric Optical Surfaces and Components

PI: James Trolinger, Ph.D./MetroLaser – Irvine, CA

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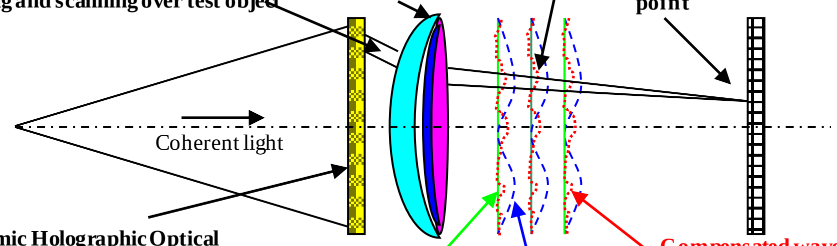
Proposal No: 06-2-S4.04-9893

Identification and Significance of Innovation

The Phase I project demonstrated feasibility of:

•A unique combination of two powerful, null point, inspection techniques, Hartmann and digital holographic interferometry enabled with a dynamic holographic optical element.
•Removing existing limitations of Hartman and interferometry.
•Preconditioning test wavefronts to compensate for predicted wavefront distortion by a perfectly manufactured part.
•digital holographic interferometry and electronically Scanned Hartmann sensor to measure difference between perfect and imperfect optics..
•Virtually unlimited dynamic range.



Phase II Technical Objectives and Work Plan

Build upon the successful Phase I effort, to produce, demonstrate, and deliver a combined, dynamic, Hartmann/Digital Holographic interferometry inspection system and complete software for a wide range of advanced optical components, including aspheric optics such as X-ray telescope mirrors. The measurement will determination wavefront errors to within a fraction of a wavelength. Such optics do not lend themselves to conventional diagnostics for several reasons, such as asphericity and segmentation.

NASA Applications

•Could be extremely valuable in manufacturing and acceptance testing of a wide variety of optics.
•Can provide new standards for manufacturing and quality control.
•Can have widespread impact on the performance capabilities of the many NASA optical systems.
•Will provide substantial cost benefits compared to alternative, more complex, and expensive solutions.

Other Applications

•US Army, Navy, & Ballistic Missile Agency-Inspecting a new generation of infrared aspherics and freeform optics.
•Optical systems employed in security monitoring, marine observation and metrology. **Firm Contact**: Dr. James Trolinger, 949-553-0688, ext. 225 jtrolinger@metrolaserinc.com

NON-PROPRIETARY DATA