HOLOGRAPHIC OPTICAL ELEMENT FOR LIDAR SCANNING SYSTEMS

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1/27/24

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ENGINEERING FORWARD

PHOTONICS WEST

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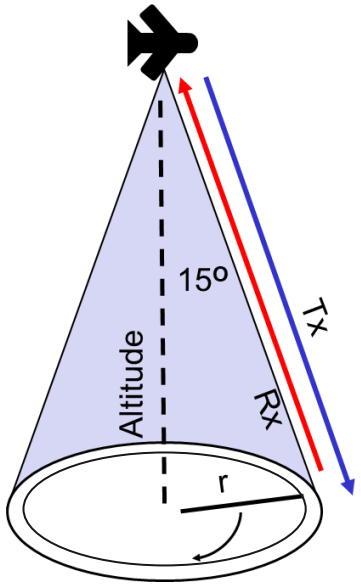
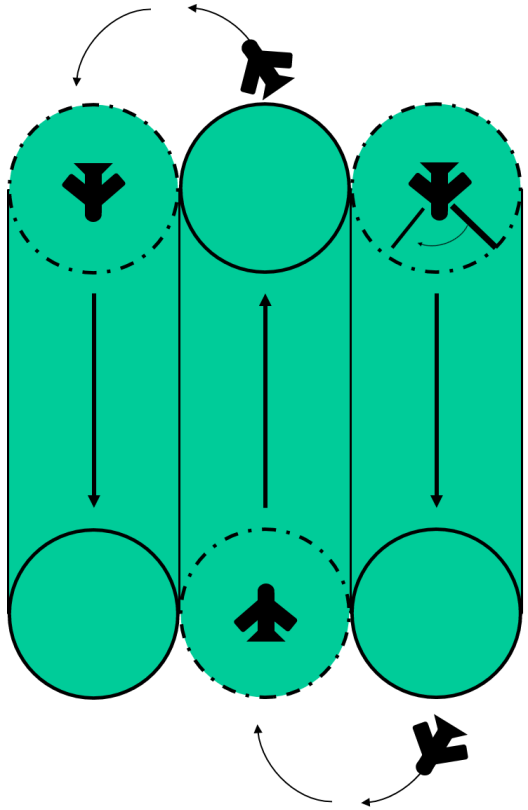
Airborne Conical Scanning

Rotating refractive wedges generate a conical scan determined by Snell's law, a function of refractive index and wedge angle. Rotation about a symmetric axis can result in an asymmetric moment of intertia that can limit the deflection angle of the scan.

Conical Scan

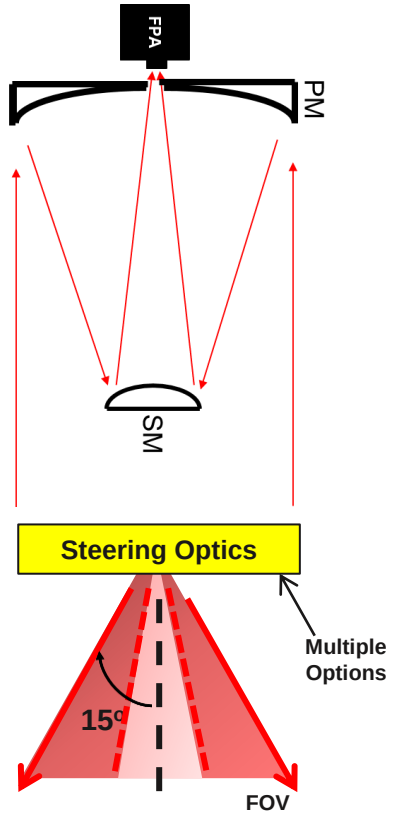


Flight Path

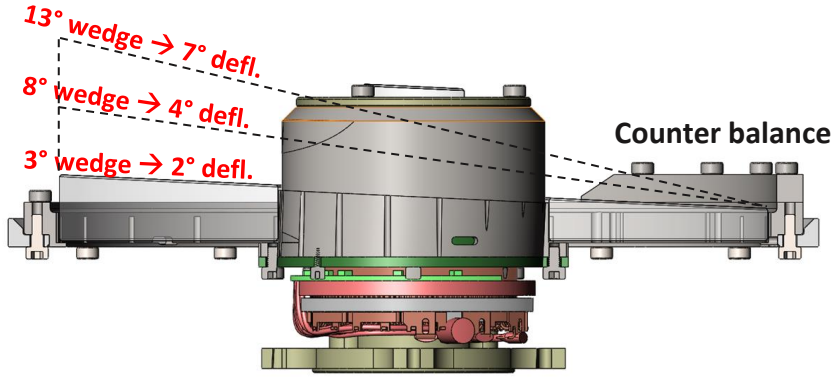


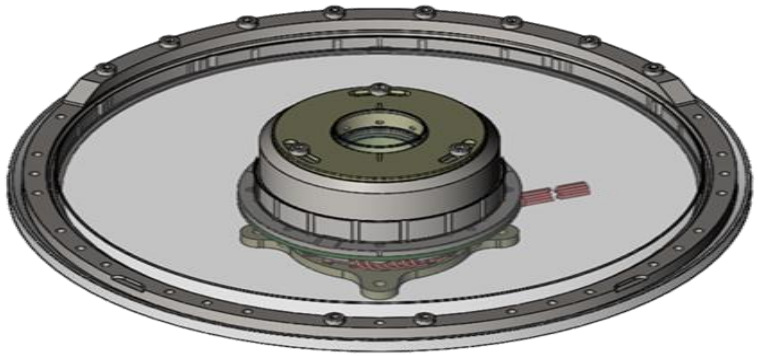
Conical scan gathers data from fore and aft of airborne vehicle

Telescope and Scanning Architecture



250mm Front End Refractive Scanner





Scanner is comprised of fused silica and suitable for scanning at 1500rpm for a 1064nm Tx source

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HOLOGRAPHIC ARCHITECTURE

A hologram can be characterized as a periodic structure with a phase modulation based on the interference of two beams. The phase modulation is dictated by optical path difference, or in this particular case the modulation of refractive index through a constant medium.

Integrating a holographic optical element as the scanner, we can generate a conical scan that mitigates that asymmetry of a refractive wedge.

Recording

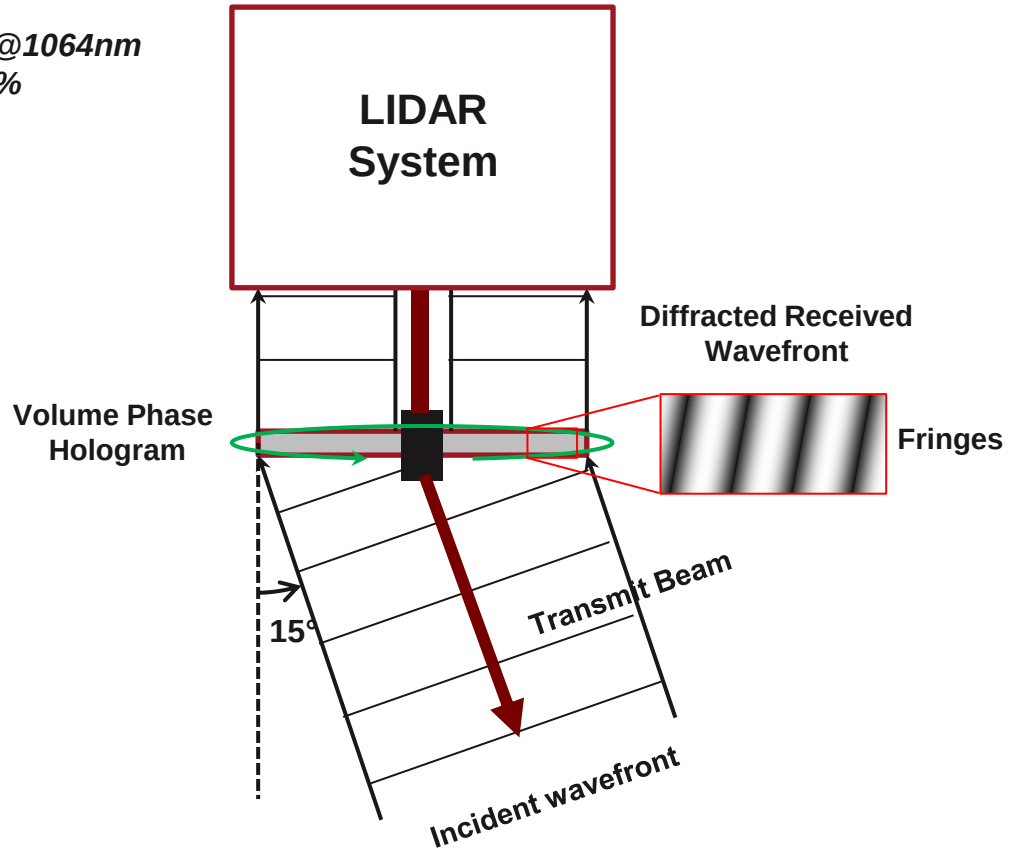
Readout

+1 diffraction order

Trade off: throughput efficiency due to diffraction, and wavefront error

Wavefront spec: λ/8 RMS @1064nm
Diffraction Efficiency: >60%

Holographic LIDAR Scanner



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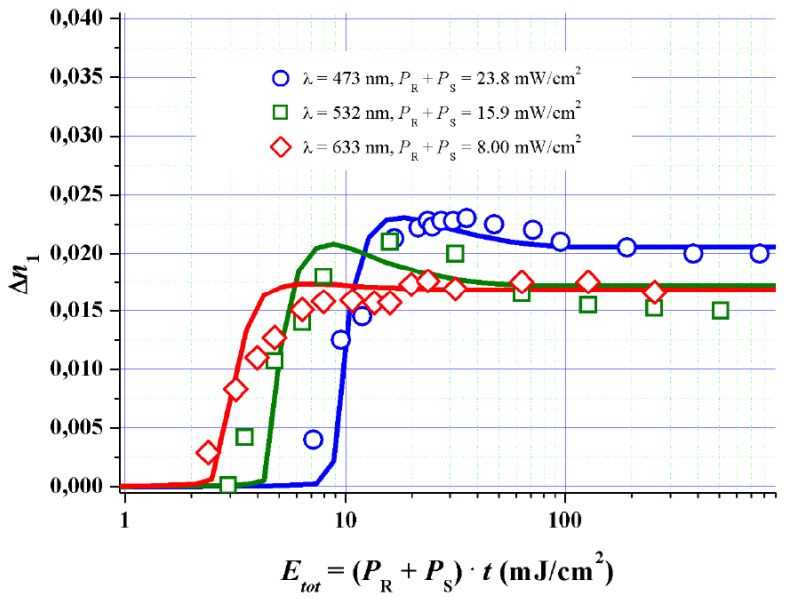
Holographic Material Selection (Hx Bayfol)

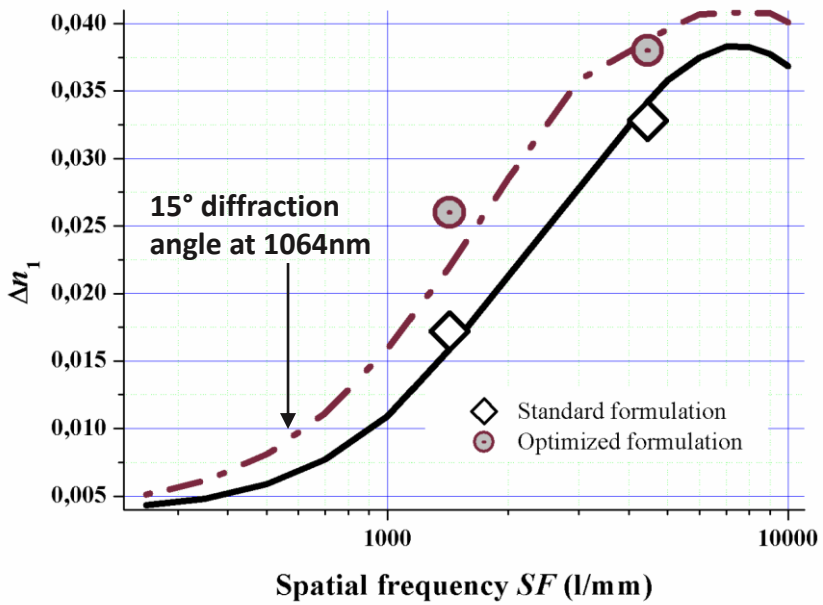
Volume holograms based on DCG and Photopolymers can achieve upwards of 90% diffraction efficiency and high spatial frequency. Photopolymers offer an advantage in removing the need for 'wet' processing. Modulation depth is a function of refractive index difference.

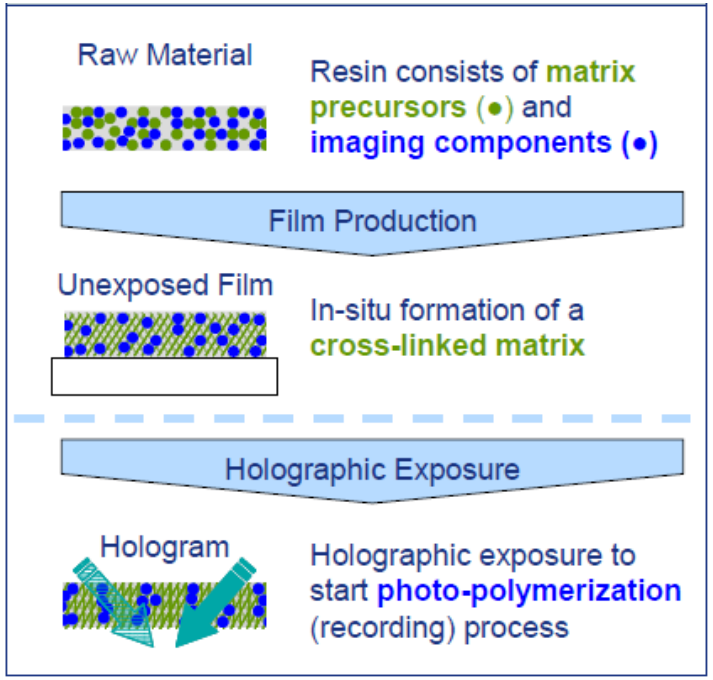
Material	Exporsue (J/m^2)	Resolution (mm^{-1})	Processing	Efficiency
Dichromatic Gelatin	10^2	10000	Wet	0.90
Photopolymers	$10\text{-}10^4$	5000	Dry	0.90

Modulation depth as a function of total energy



Modulation depth based periodicity





Diffustion of mononers is a function of periodicity of fringe patter. The larger the periodicity, the less the diffffusion process, less difference in refractive index between peaks and valleys of interference fringes.

"Reaction-diffusion model applied to high resolution Bayfol HX photopolymer"
"Holographic recording aspects of high-resolution Bayfol® HX Photopolymer"

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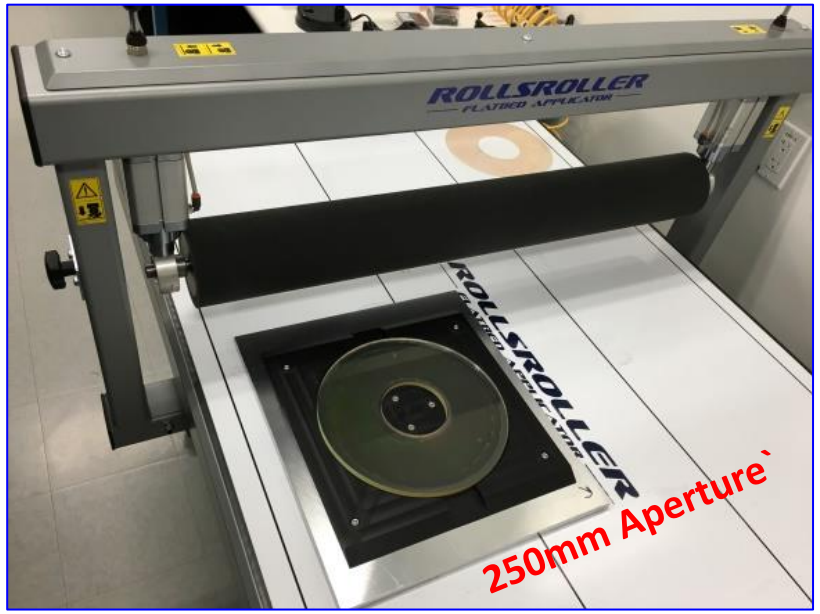
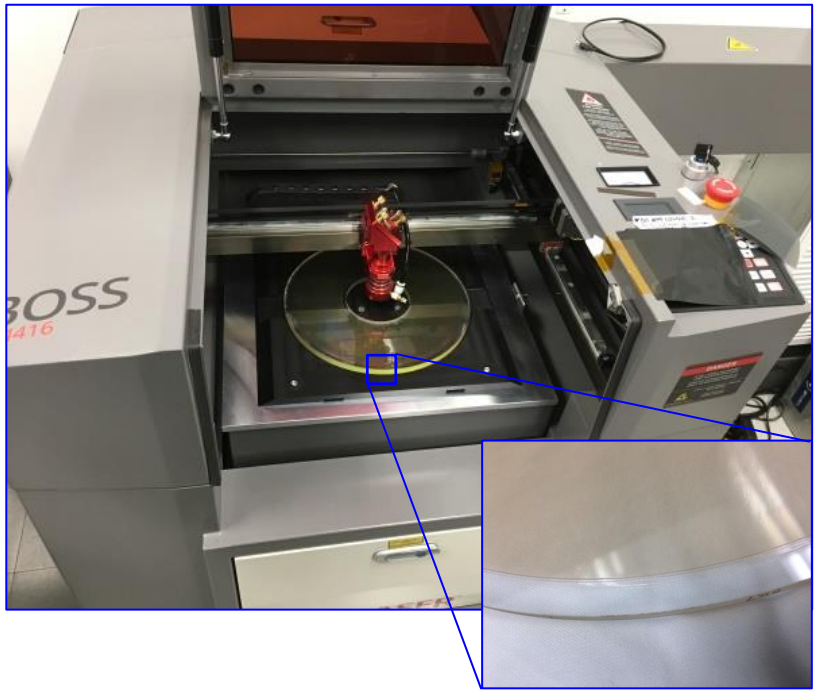
Recording Process and Yield

Application of film



Laser Cutting Film



Working Conditions

Applying the film is a delicate process due to the potential for wrinkles and delamination to occur at any step in the process undoing weeks worth of effort.

Laser cutting the film seals the edge to prevent glue from creeping through on the underside of the film that would also cause delamination

Low level red light allows for handling the film openly without exposing it to a high enough intensity that it would otherwise record

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Optical Setup

Expanding the beam to 12" OAPs to collimated two beams and record the fringe pattern on the target. Exposure times of 60-80ec were used to achieve the diffraction efficiency requirement. Recording angles should be scaled based on recording wavelength, slant angle, and targeted periodicity.

Schematic for Holographic Recording

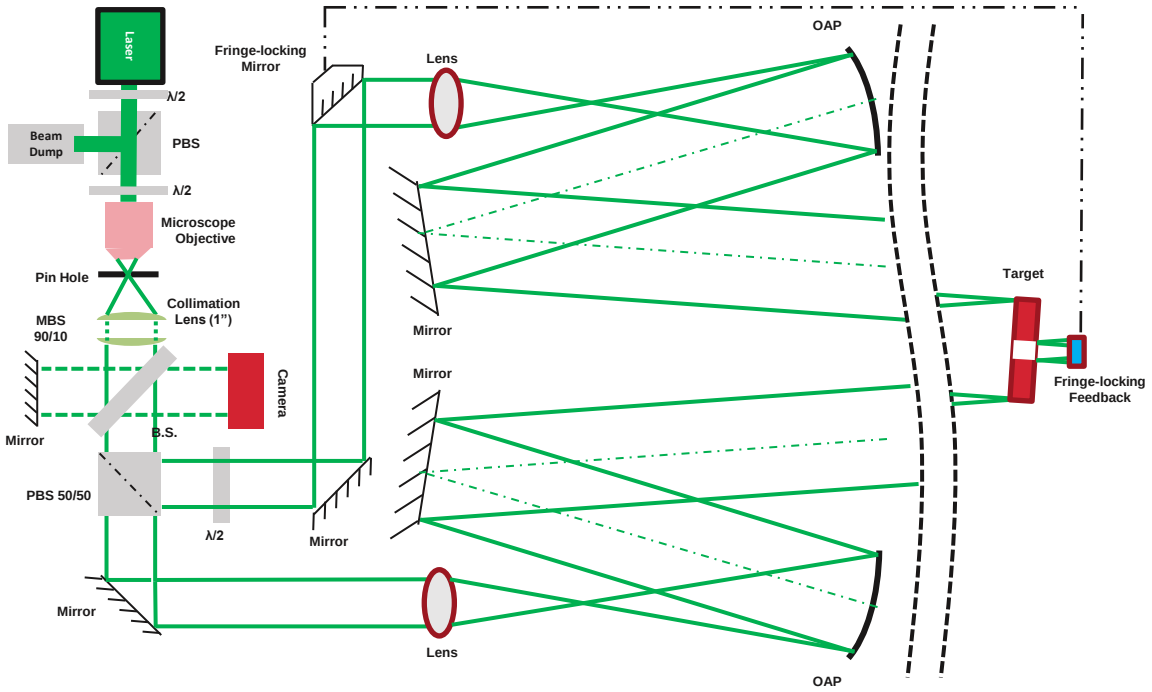
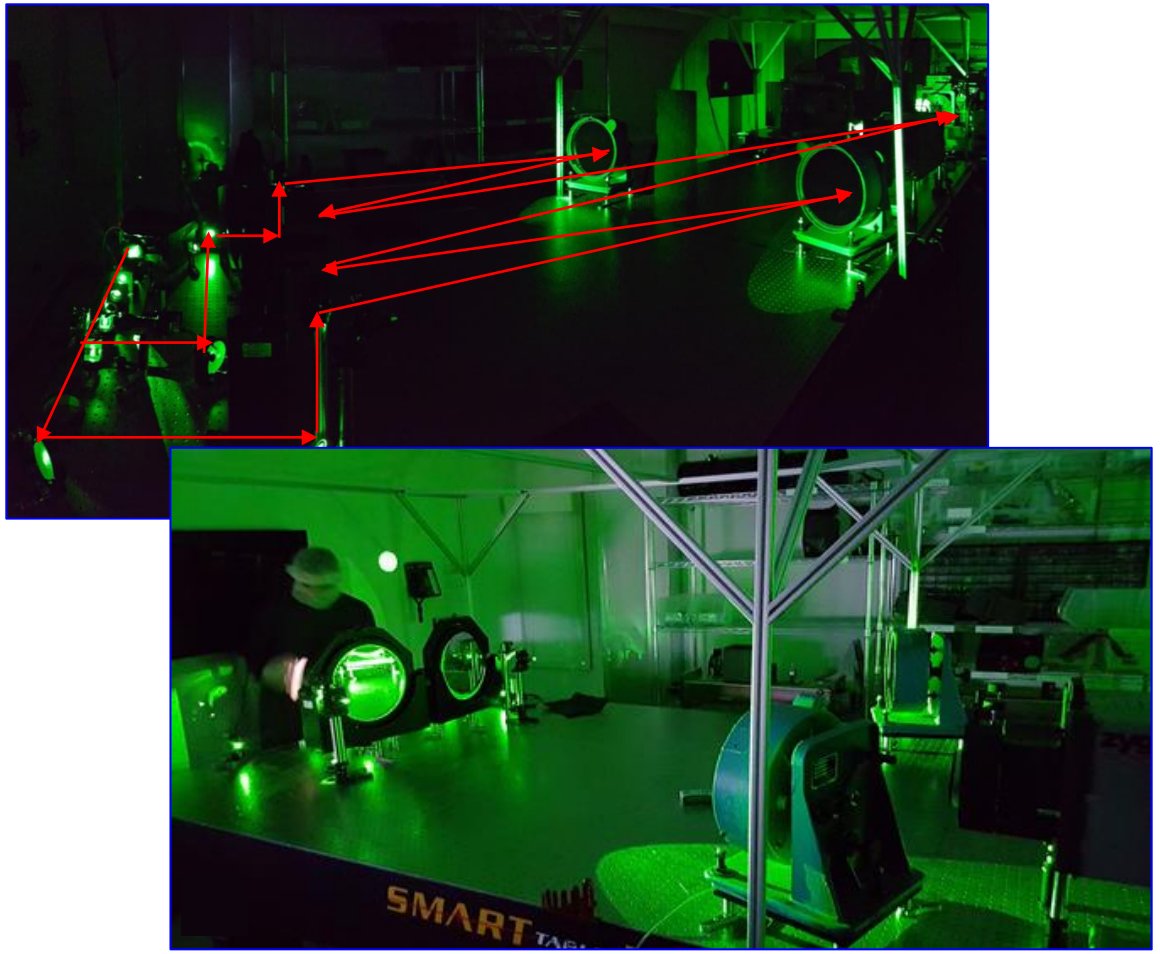


Image of Holographic Setup



Scintillation between channels can result in fringe contrast degrading due to rapid changes in optical path length between channels.

Intermediate interferometer aids in measuring wavefront error of each beam

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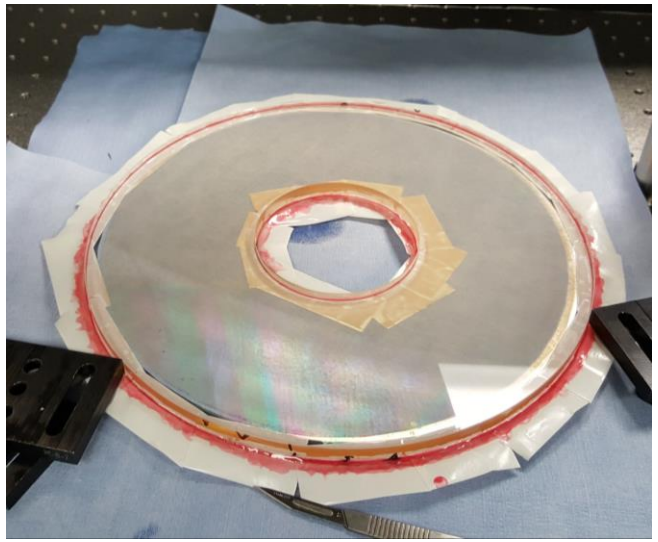
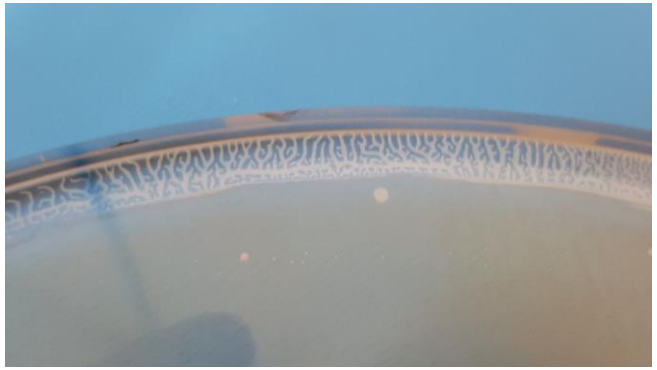
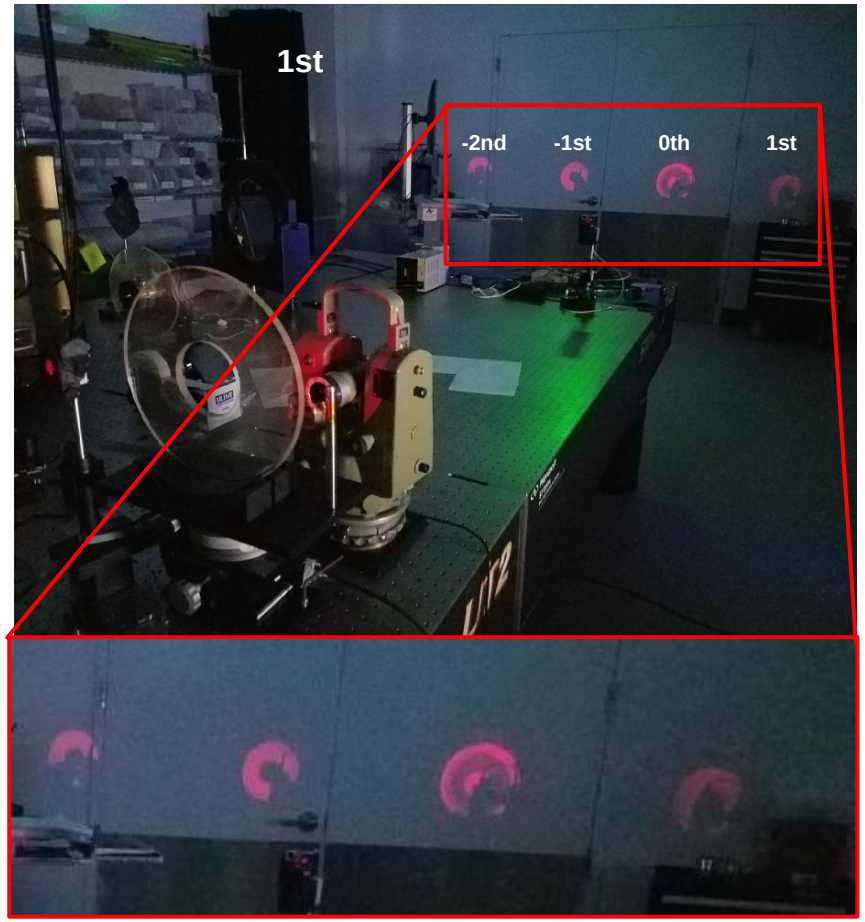
Sandwiching Process, Warping, Zygo Measurement

UV Epoxy bonds two pieces of glass together to protect and index match the photopolymer





Interferometric measurements at 633nm of the 1st order diffracted beam to characterize wavefront error of scanner



Bonding two large pieces of glass with a photopolymer layer results in a warped surface figure and has detrimental impact on optical performance

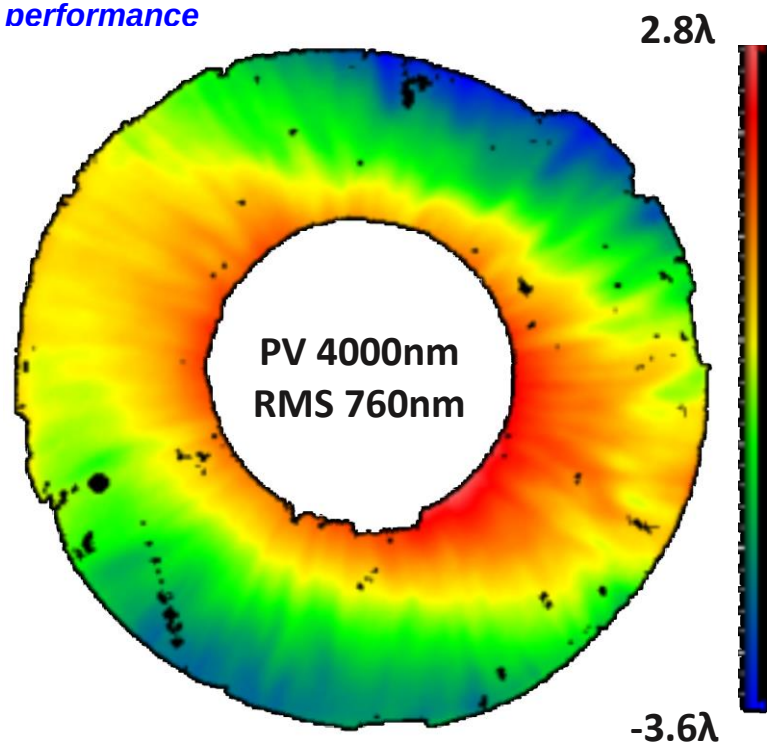


Illustration of HOE after Sandwiching

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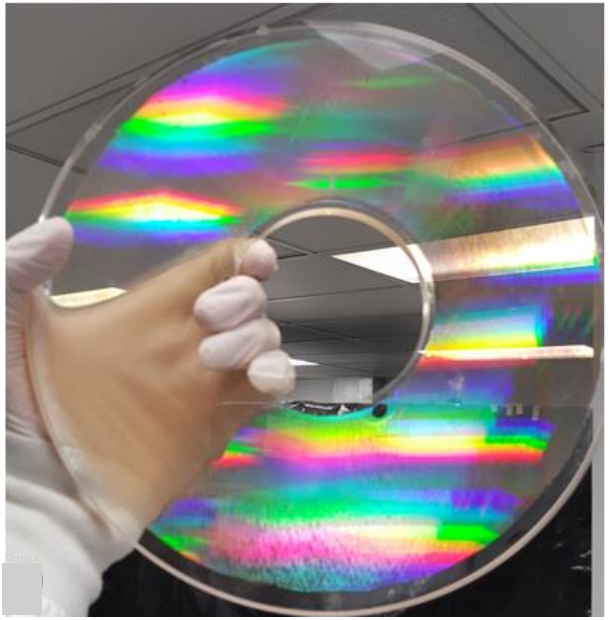
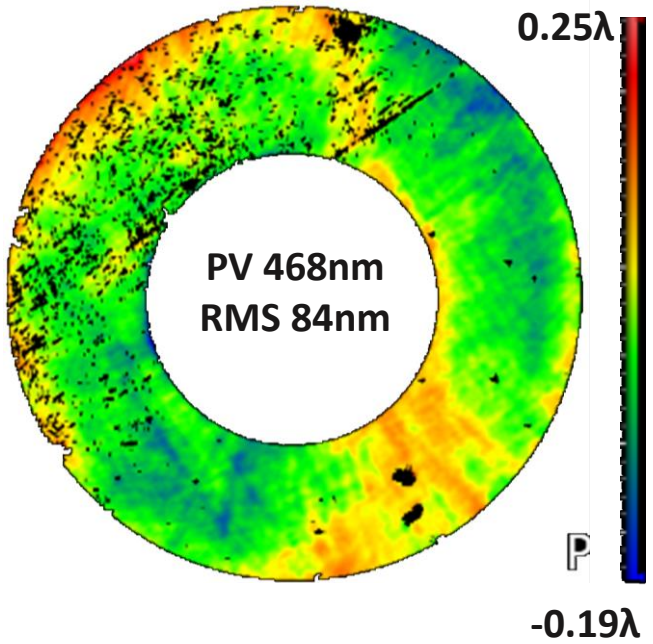
Post-Polishing and Measurements

Double Side Polishing

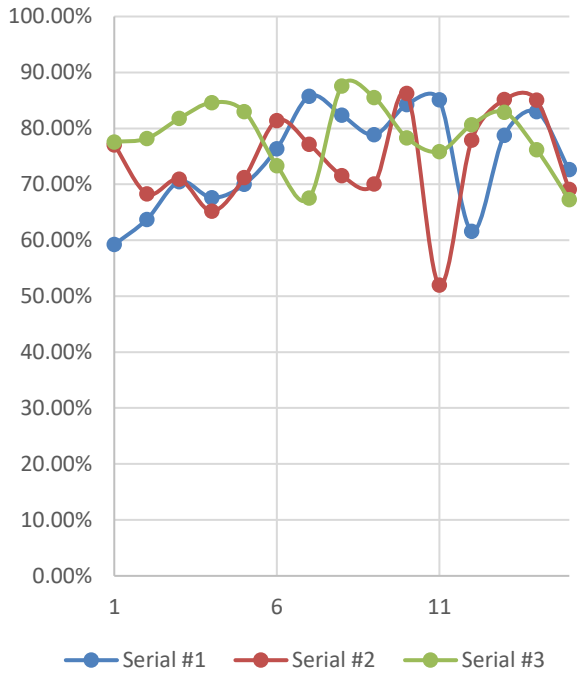
Completed HOE

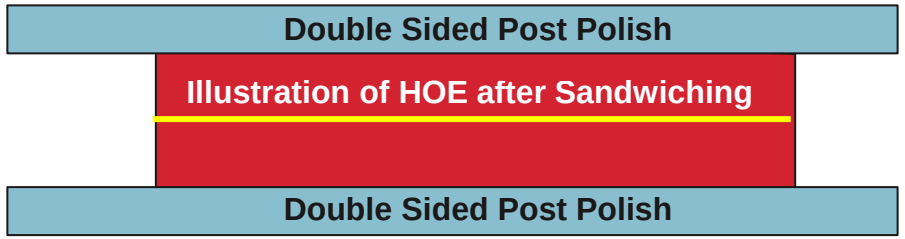


Post-Polishing Zygo Measurement



Diffraction efficiency measurements





Zygo measurement of 1st order diffraction after post polishing and AR coating scaled for 1064nm.

Diffraction efficiency measurements were conducted with a 1" collimated source by measuring points radially across the optic with a 1064nm laser source. Average diffraction efficiency achieved was 75% in the first order

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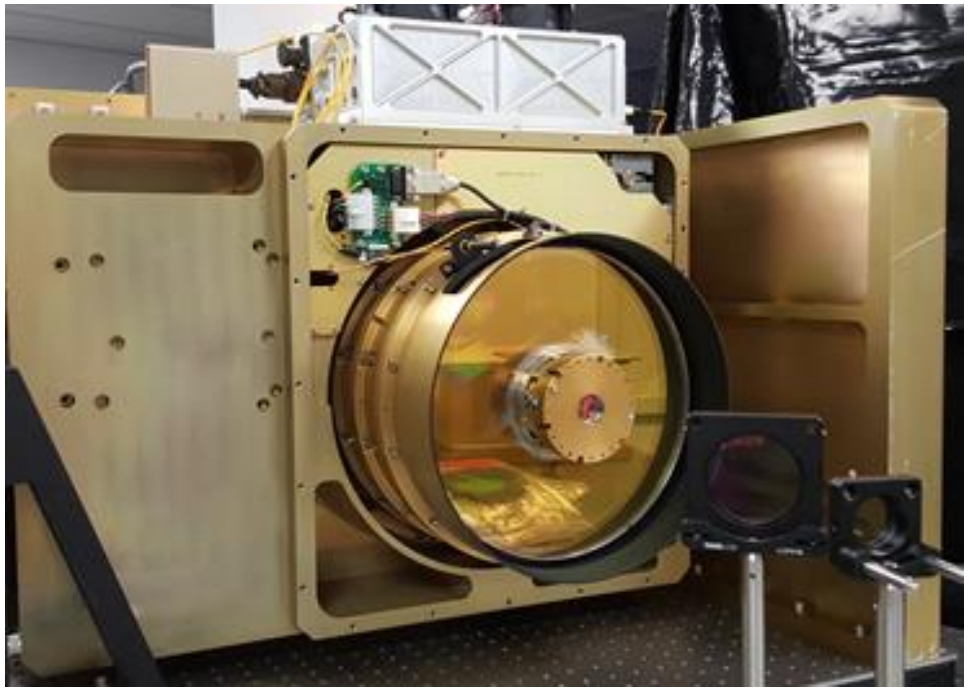
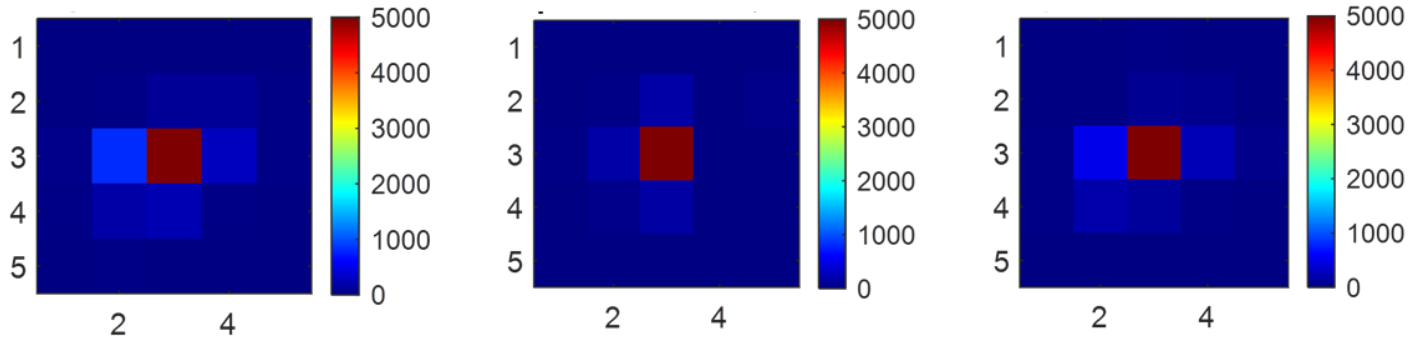
VALIDATION AND TESTING

The transmitted beam of the LIDAR system was redirected into the receive aperture through the scanner to evaluate performance. Ensquared energy was evaluated to predict imaging performance.

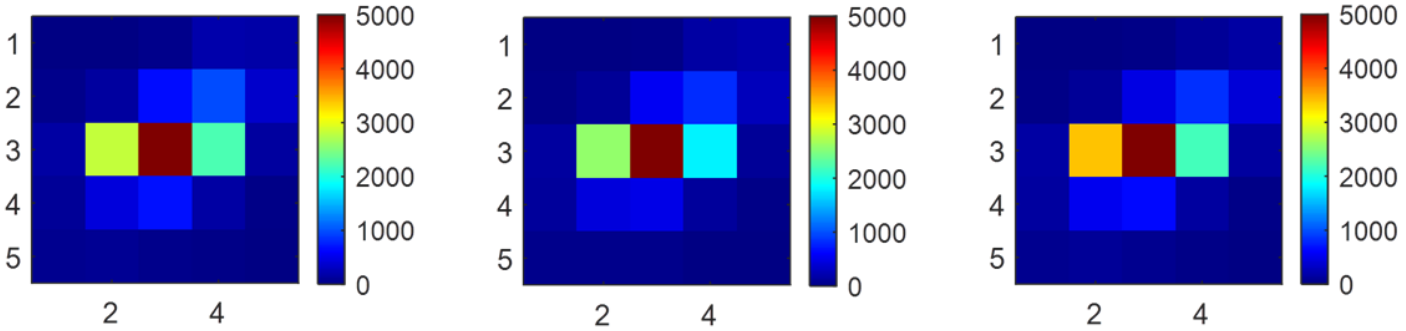
Integrated HOE in LIDAR System



PSF on Camera WITHOUT Holographic Scanner (83% Ensquared Energy for a 50µm pixel pitch)



PSF on Camera WITH Holographic Scanner (50% Ensquared Energy for a 50µm pixel pitch)



The spread in the PSF after integrating the scanner can be attributed to the 0.3nm linewidth the of laser. With a 1400mm focal length and the scanner set at the entrance aperture of the optical system, the laser's linewidth spreads over to neighboring pixels.

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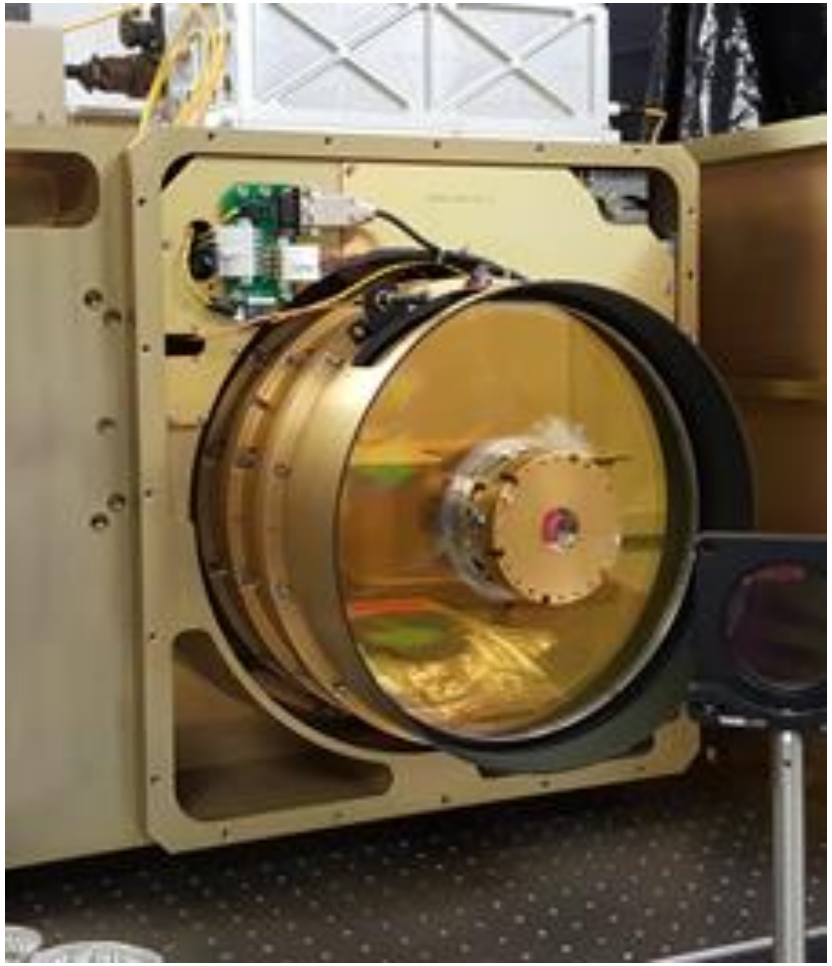
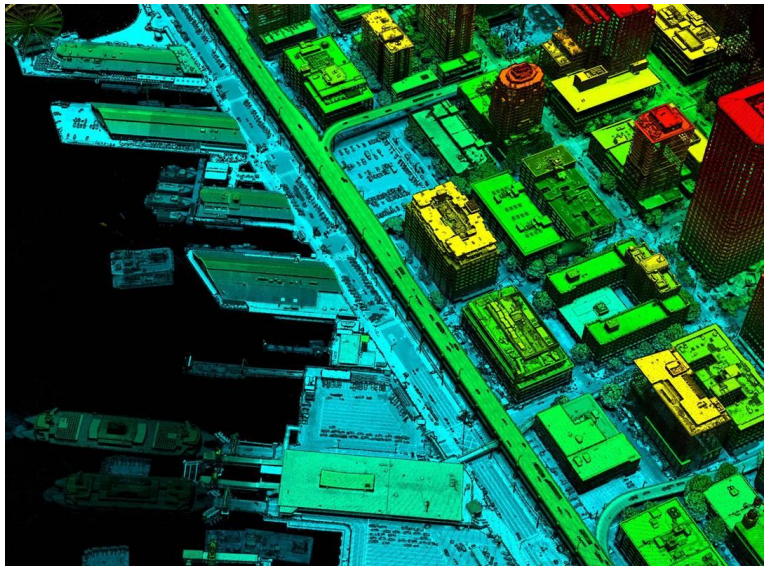
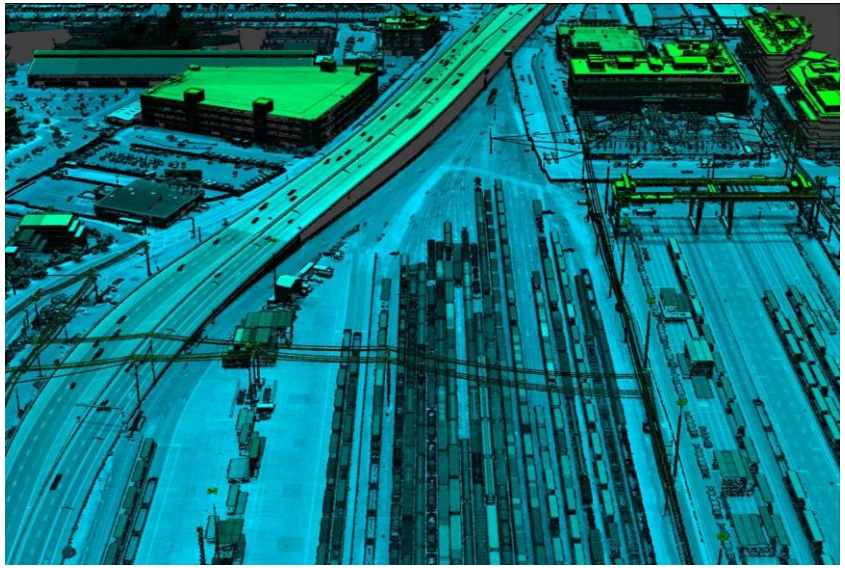
Operational Performance

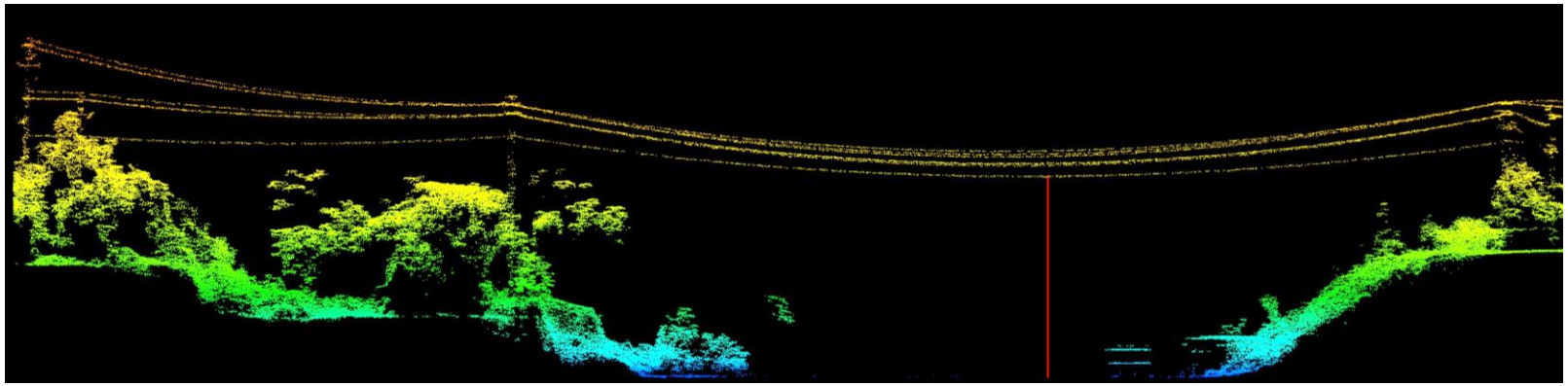
Integrated HOE in LIDAR System



3D Point Cloud Images (Provided by VeriDaaS)







HOE is spun at 1400 RPM and scanning the ground at an altitude of 13,000 feet with a coverage of 50ppm, and a height resolution of 10cm.

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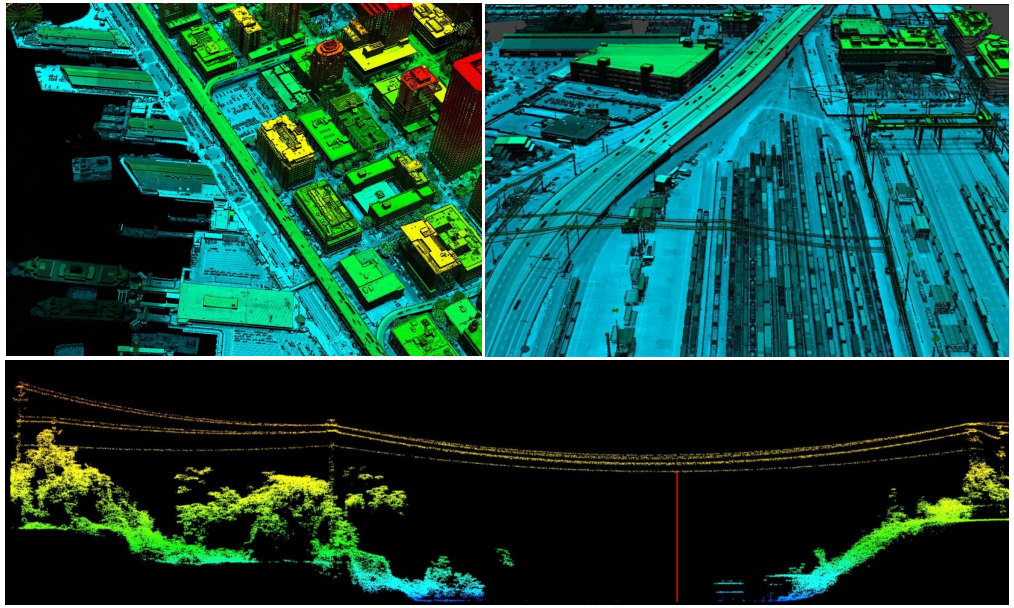
Conclusion and Acknowledgements

- Quartus developed and built 3 LIDAR systems with holographic scanners that are currently operational
- Previously owned by L3Harris, VeriDaaS are the current owners of the technology and we are grateful for their participation in the presentation and providing these recent images
- We would also like to give a big thanks to individuals that have made great contributions this development:
  - Cameryn Yow
  - Mike Ricci
  - Brad Steele
  - Thomas Fäcke
  - Mike Naselaris



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