Rendering Spatio-Temporal Dynamic of Deformable Mirrors

V. Markov, A. Khizhnyak, J. Kilpatrick, J. Weldon
Advanced Systems & Technologies, Inc.

G. Osborne
Naval Air Warfare Center Weapon Division

Irvine, CA 92618
www.asatechinc.com

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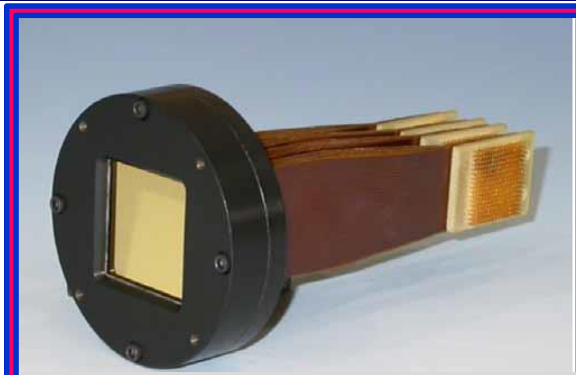
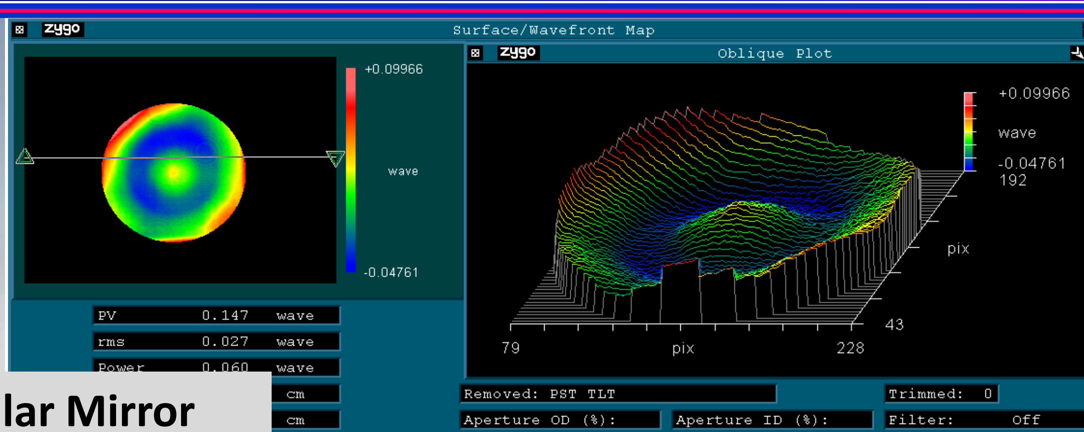
Outline

- **Motivation:** **An operational High-Energy Laser (HEL) to be deployed by 2021**
  - Deformable Mirrors (DM) are key for Beam Control
  - DM's parameters are critical for Adaptive Optics
  - Various types of DM have to be evaluated
- **Problem to be addressed:** **<u>Technology for DMs performance characterization</u>**
  - System Specification
  - Performance requirements
  - Breadboard
  - Proof of the concept demonstration
- **Existing solutions:** **<u>Optical Technologies for Dinamic Surface Profilometry</u>**
  - Incoherent: Time of Flight, Laser Scanning, SHWFS
  - Coherent : Holographic, Laser Doppler Velocimetry
- **AS&T Solution:** **<u>Technology Background</u>**
  - Design approach and System architecture
  - Opto-electronic design and data processing
  - Examples of prior applications

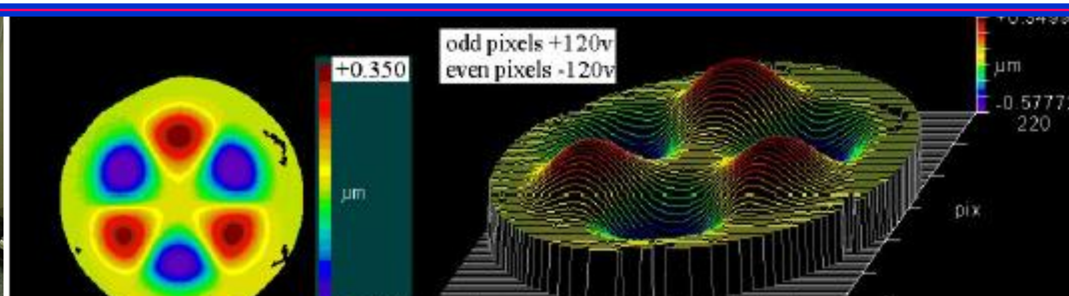
New Generation HEL Implementations

Top Level Deformable Mirrors

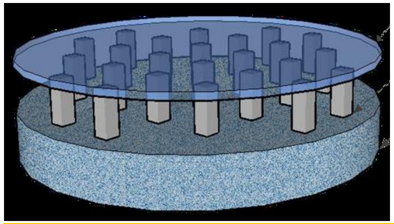




AOA Xinetics 349-ch Modular Mirror



ARL 7-pocket 49-channel DM with Controller



AOS Membrane-type DM with Controller

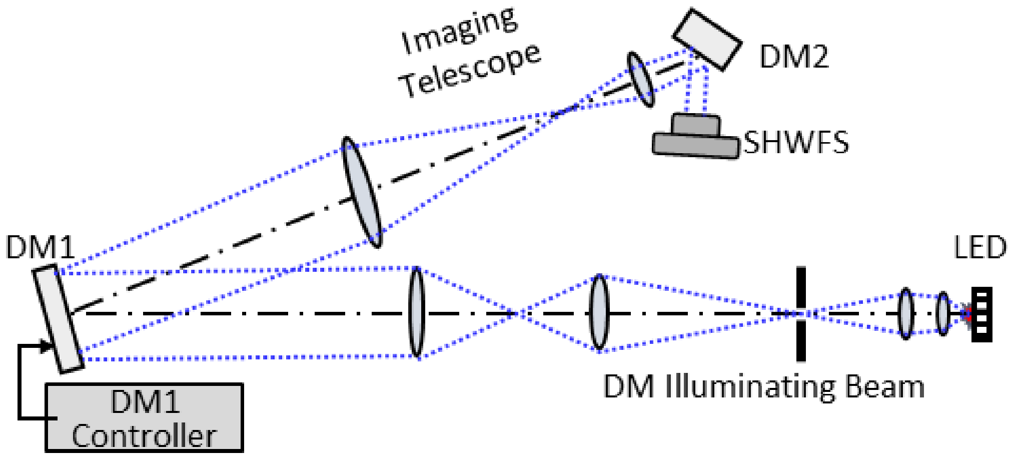
DM Technologies in Response to Tech Needs

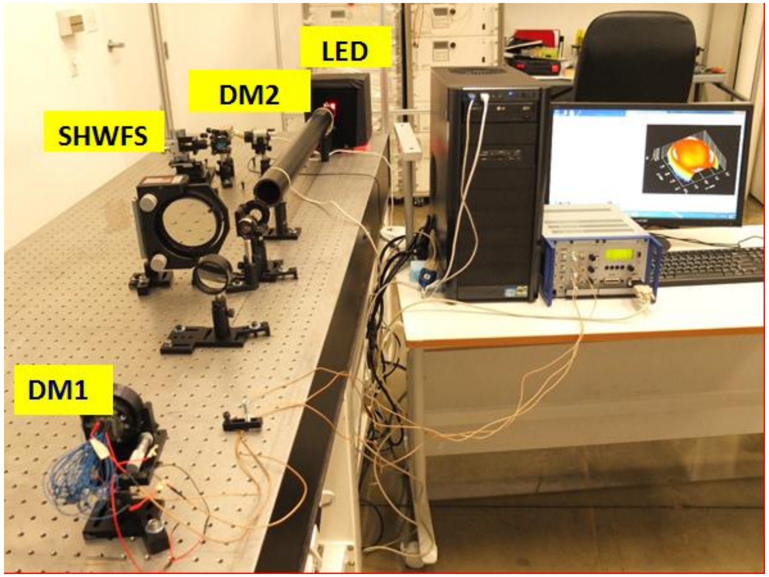
Parameter to measure	Target	ESPI	Shearo graphy	SH-WFS	Opt. Profilom
Stroke	>10 μm	Yes/No*	No	No	Yes
Stroke precision	< 10 nm	Yes	No	No	Yes
Frequency Rate	>100 kHz	No	No	No	No
Displacement	in-plane	No	Yes	No	No
	out-of-plane	Yes	No	No	Yes
Total Sag	≤ 25 μm	No	No	Yes	Yes
Spatial resolution	< 500 μm	Yes	Yes	No	Yes
Working Aperture	3”/7.6 cm	Yes	Yes	Yes	Yes
Surface reflectivity	0.5% to 100%	Yes	Yes	Yes	Yes
Surface Quality	Reflective	Yes	Yes	Yes	Yes
	Rough	No	Yes	No	Yes

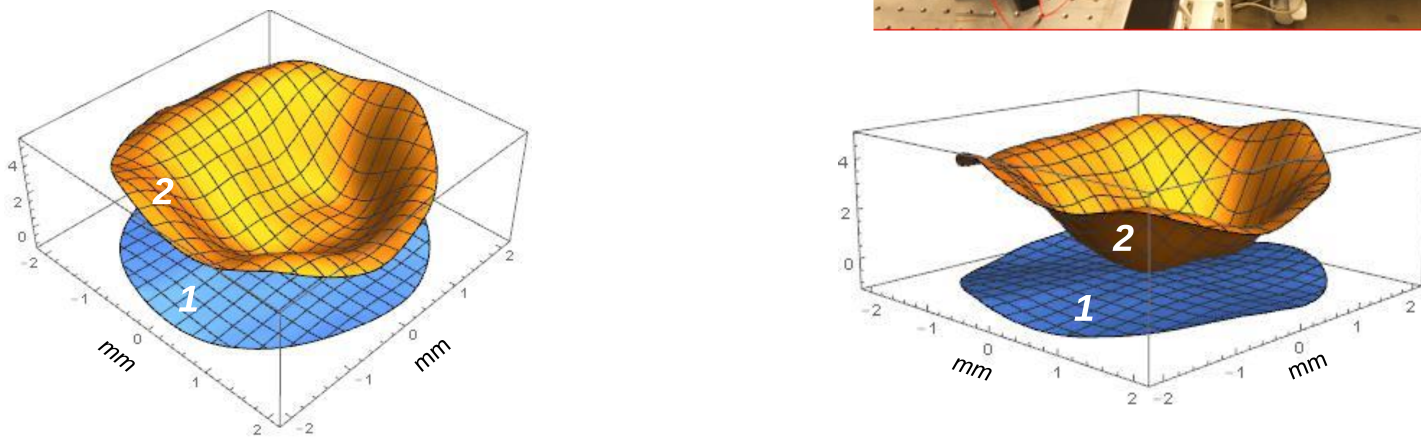
*No for a straight piston stroke

Wavefront Sensor for a SP Mode Analysis

DM Characterization Spatial Mode Sensor







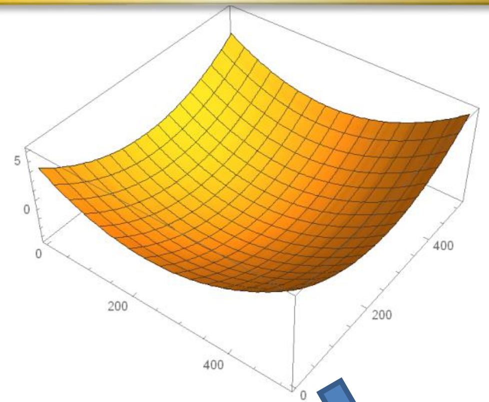
The wavefront of the reference wave reflected by a plane mirror (1) and DM2 mirror (2). The scale of the vertical axis is equal to the reference wave wavelength (λ = 625 nm).

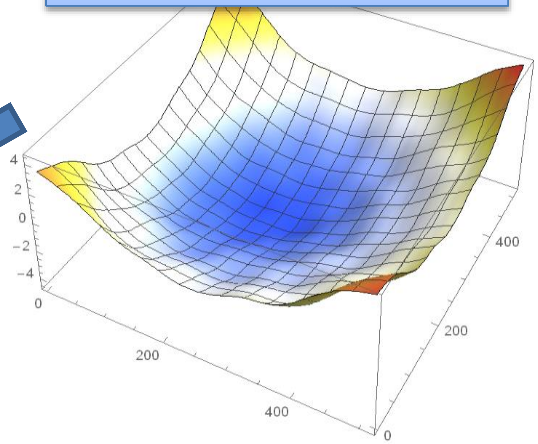
SP Mode Sensor Retrieves Spatial Variations of Wavefront

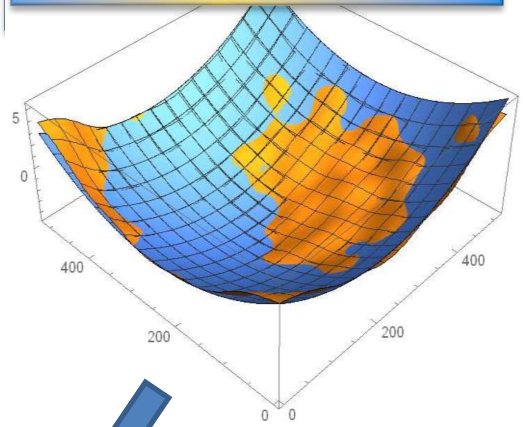
Topography of this DM has a Spherical Component

SP-Measured DM has a Complex Topography

Spherical and "Focusing" Components of DM's Topography

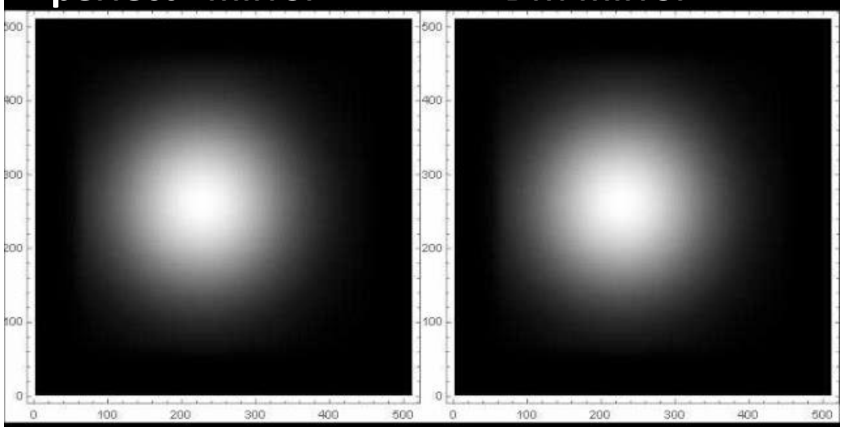




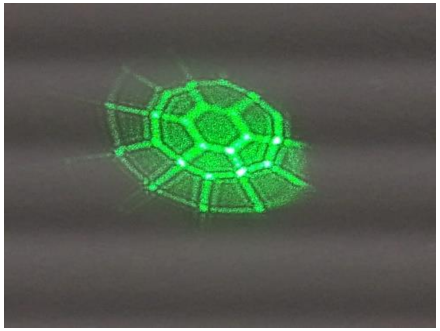


Focusing the Gaussian beam with

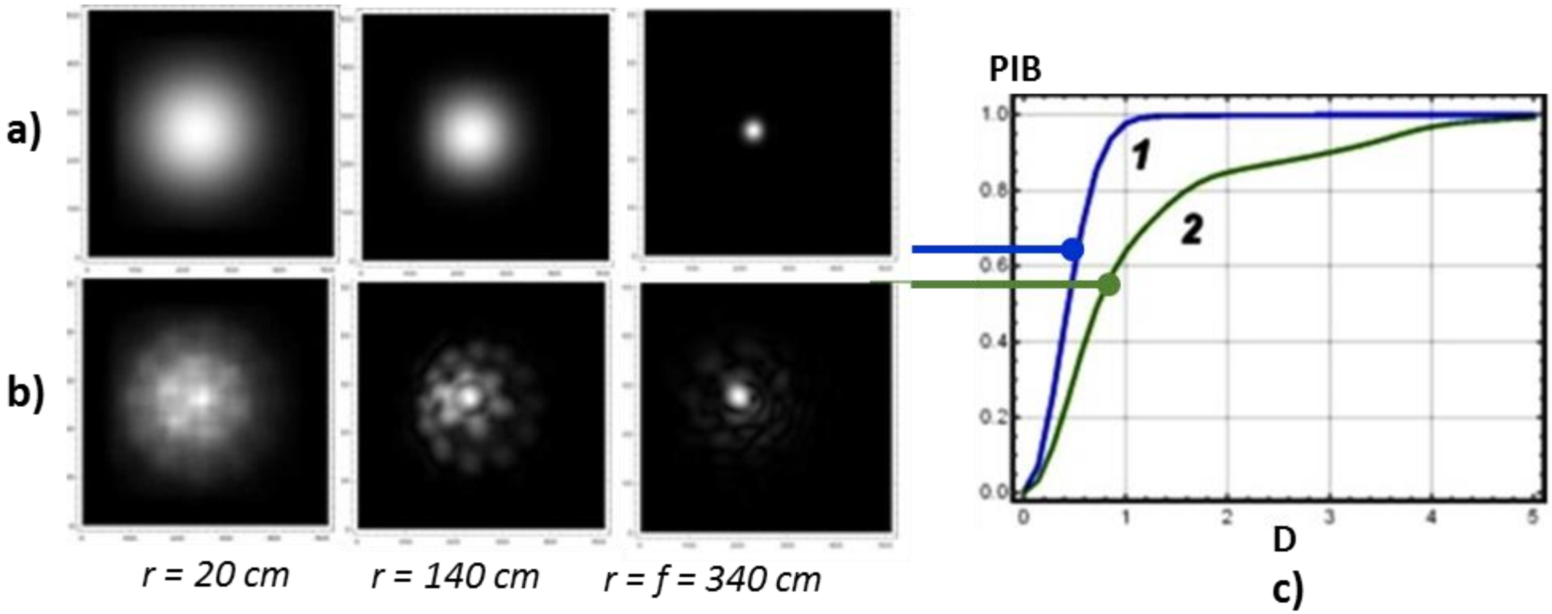
"perfect" mirror **DM mirror**



Beam reflected of Real DM



ARL Bimorph DM

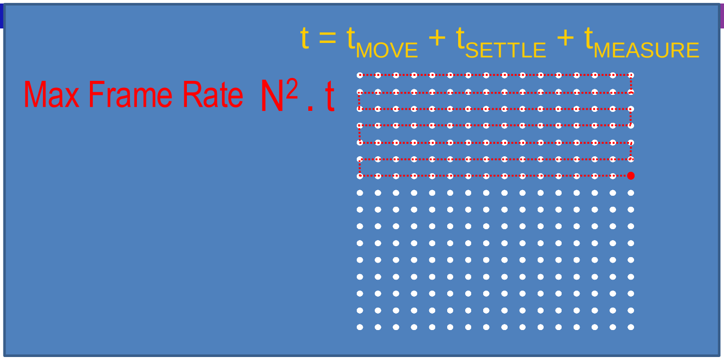


r = 20 cm *r* = 140 cm *r* = *f* = 340 cm

The results presented in the last two slides are essential!
They allow to conclude that the DMs with a non-optimal topography still can be used in their current state with no further refinement. This can be achieved by detecting the DM's topographic pattern and accounting for it in the AO system software.

Whole Field Laser Doppler Velocimeter - the Sensor for Temporal Mode Analysis

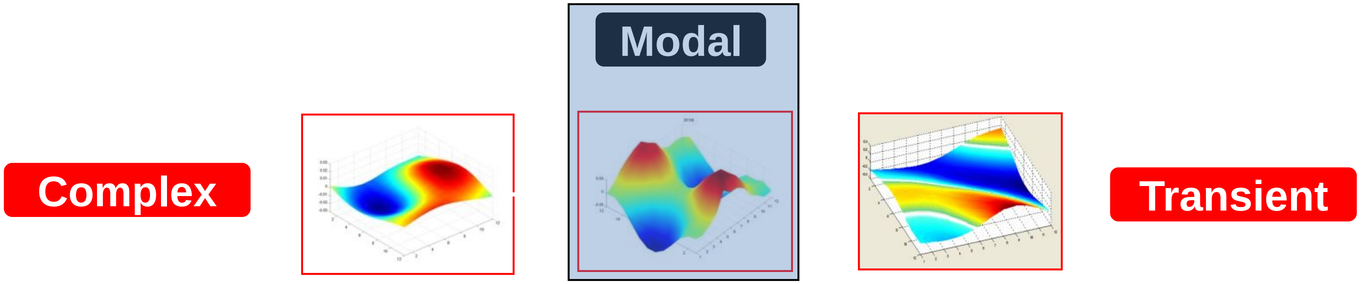
Motivation for development



- **Measurement Speed**
  N^2 times faster than single beam (N = 12 - 24)
  No mechanical scanning
  Single shot frame acquisition

- **Data Integrity**
  Short frame acquisition times > reduces baseline drift

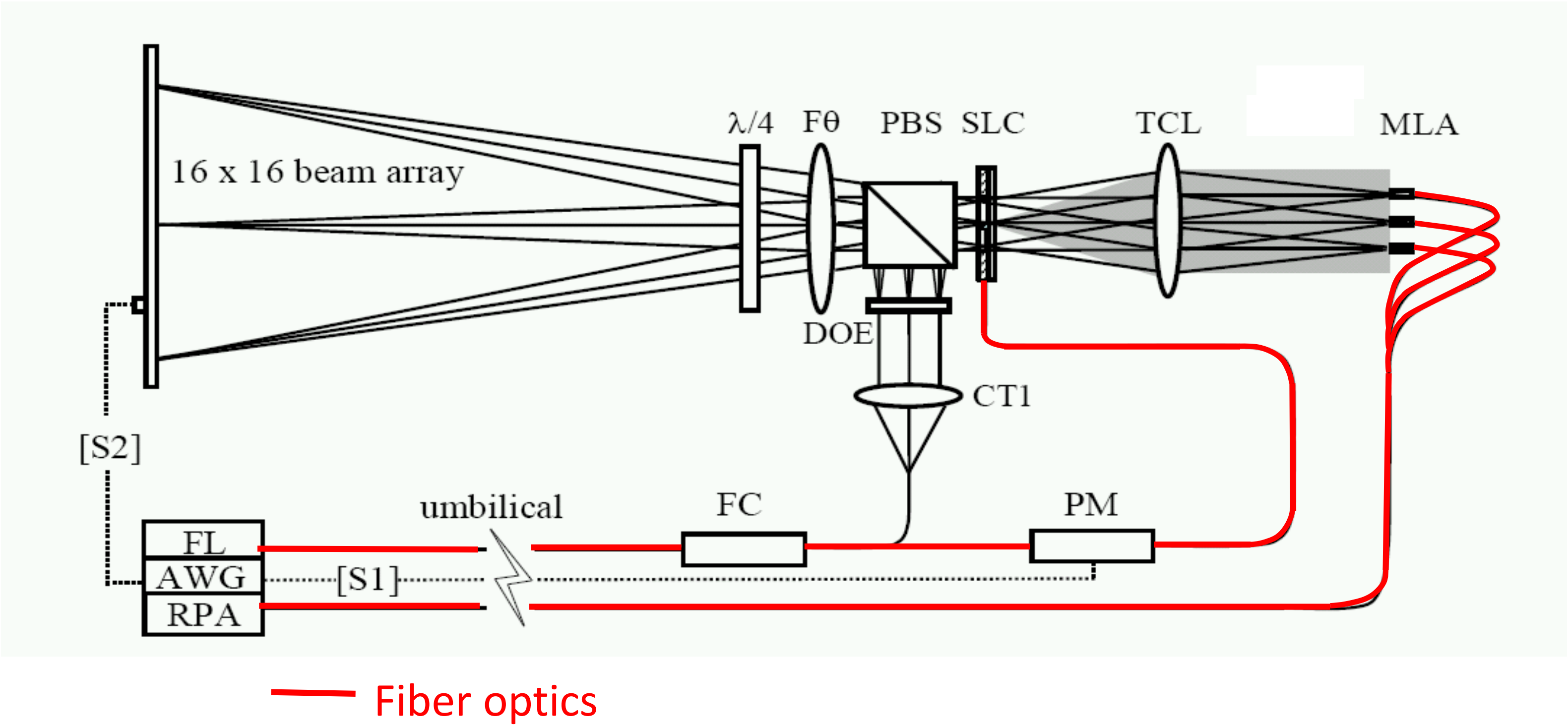
- **Transient, non-repeatable or complex motion**
  failure mechanics, impact phenomenon,
  acoustic emission, shock induced damage



- **Energy Flow in Mechanical Systems (structural intensity)**
  True vibration phase data aids understanding of energy flow between mechanical sources $\Rightarrow$ sinks.

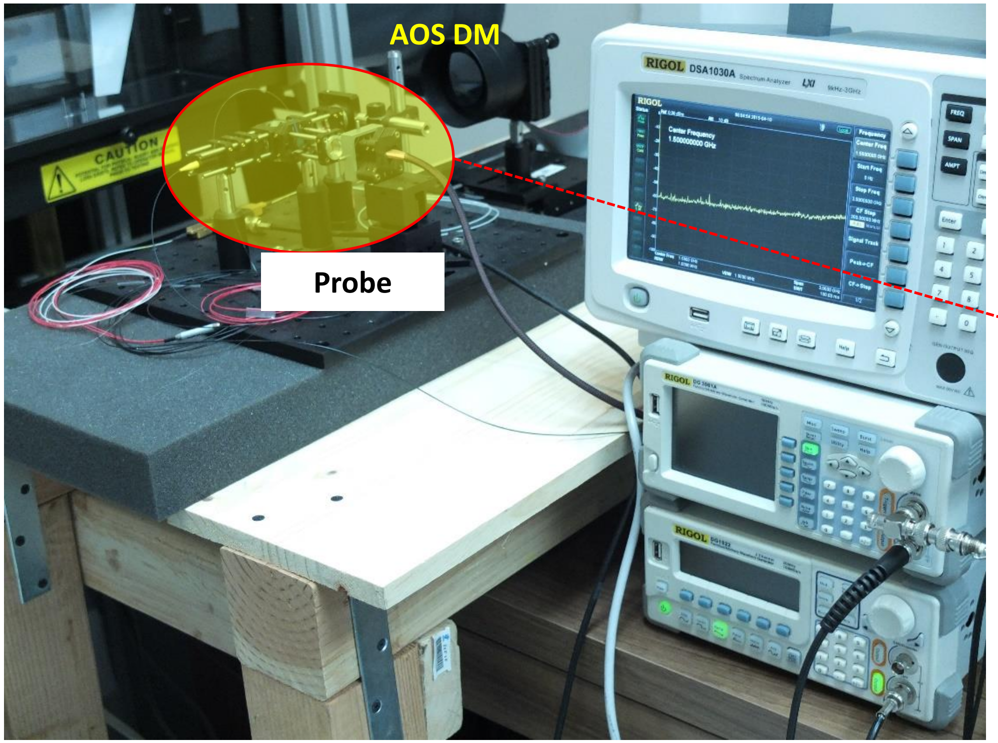
System design for Temporal Mode N x N Laser Doppler Vibrometer

~~XY scanning galvanometers~~	⇒	Staring full-field beam array (16x16)
~~HeNe laser~~	⇒	Erbium/Er-Yb fiber laser (0.1 -1.0 W)
~~Bragg cell modulators~~	⇒	Lithium-niobate waveguide modulator
~~RF drivers~~	⇒	Low power digital driver
~~Analog (hardware) processing~~	⇒	High speed parallel A-to-D / DSP

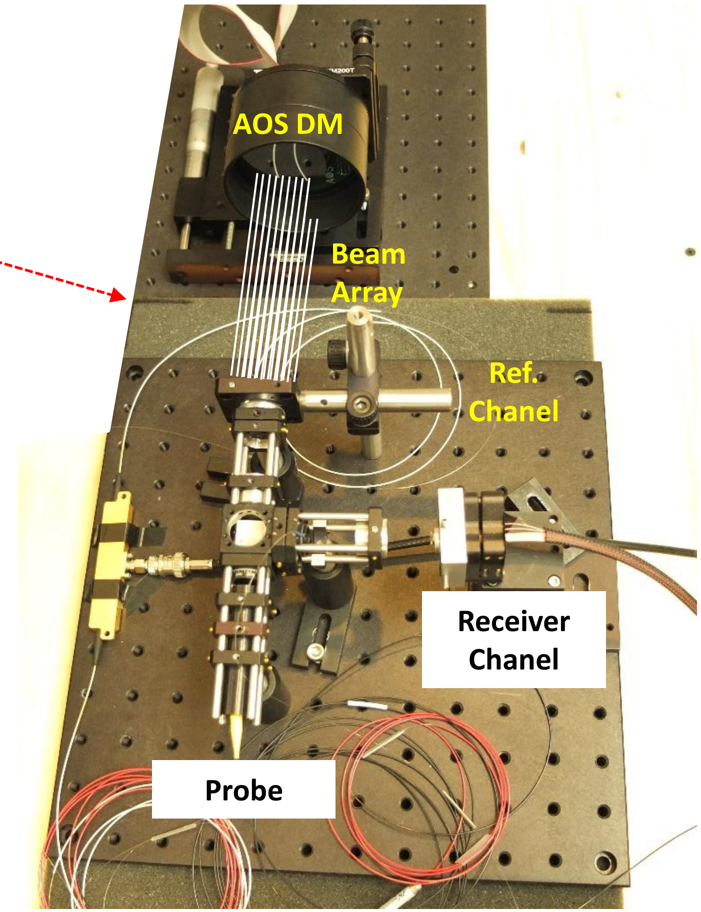


Kilpatrick, Apostol and Markov, "Design and applications of a high-speed Doppler imaging vibrometer", Proc. of SPIE Vol. 7791 77910B-1, 2010.

TM Sensor Brassboard

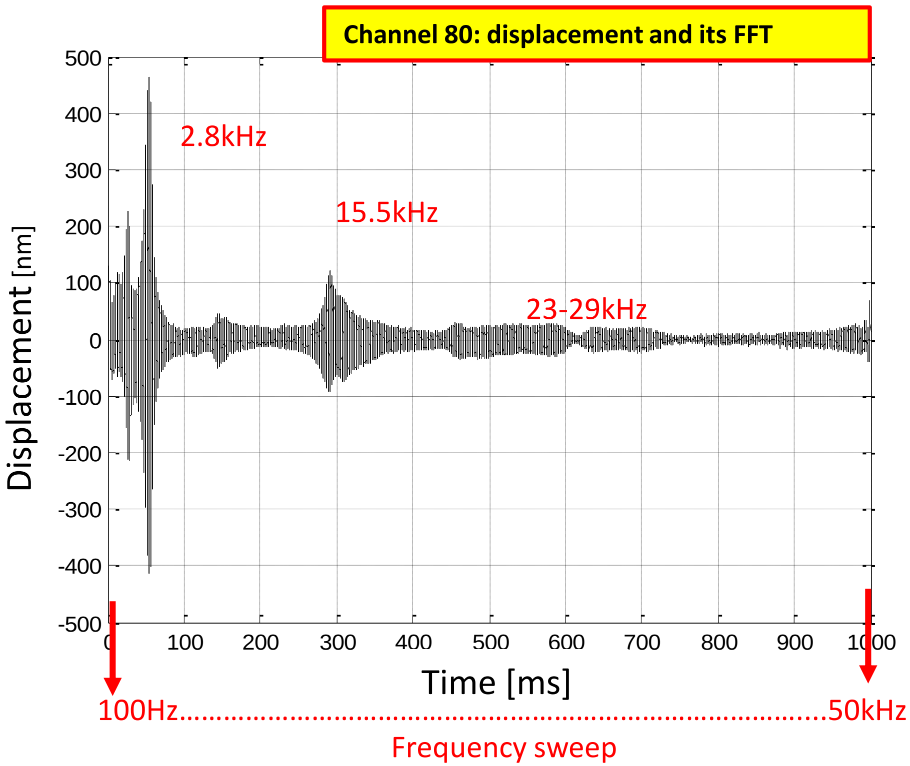


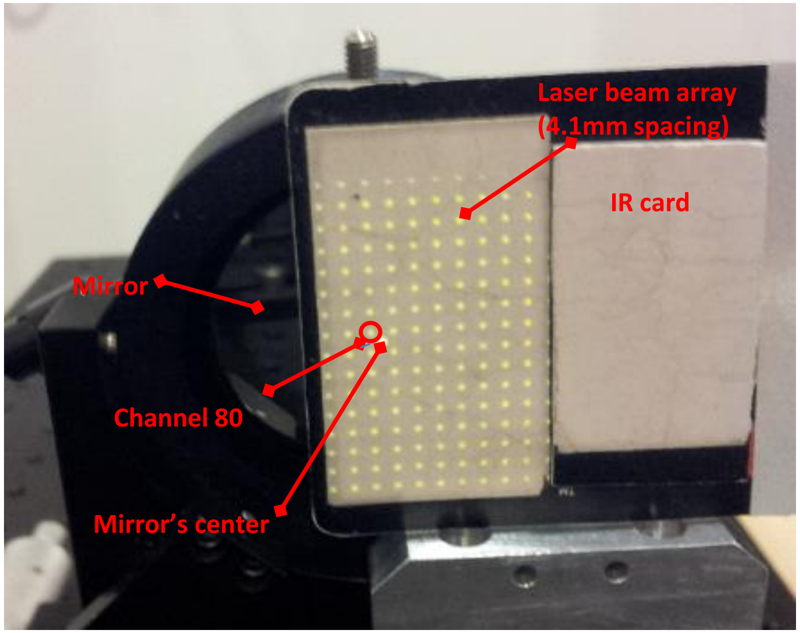
- Spectrum Analyzer
- Driver of Actuators
- Generator

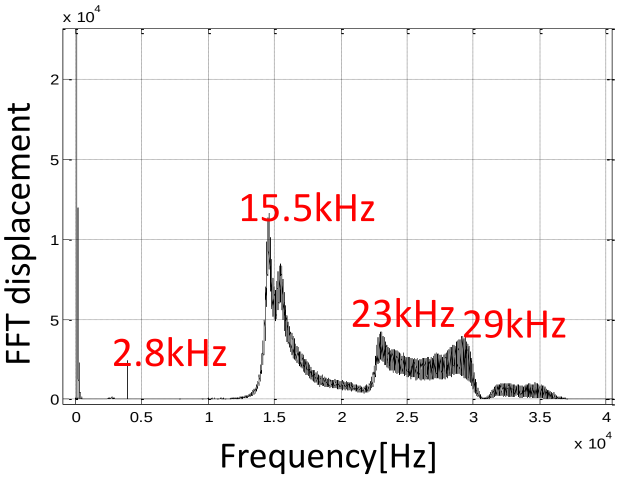


Damped Bimorph DM

Excitation : Central Pin PZT 60 V
Frequency band : sweep 0.1 – 50 kHz

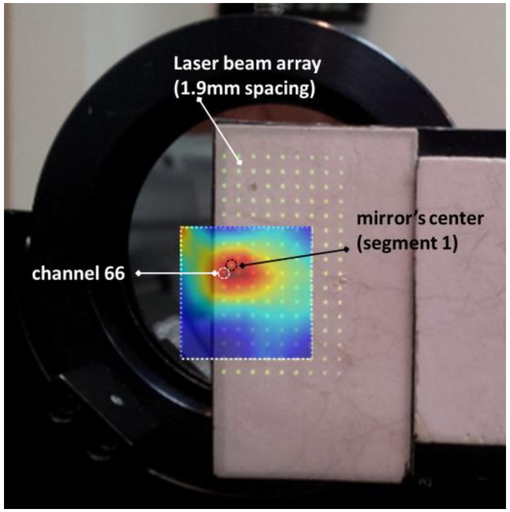






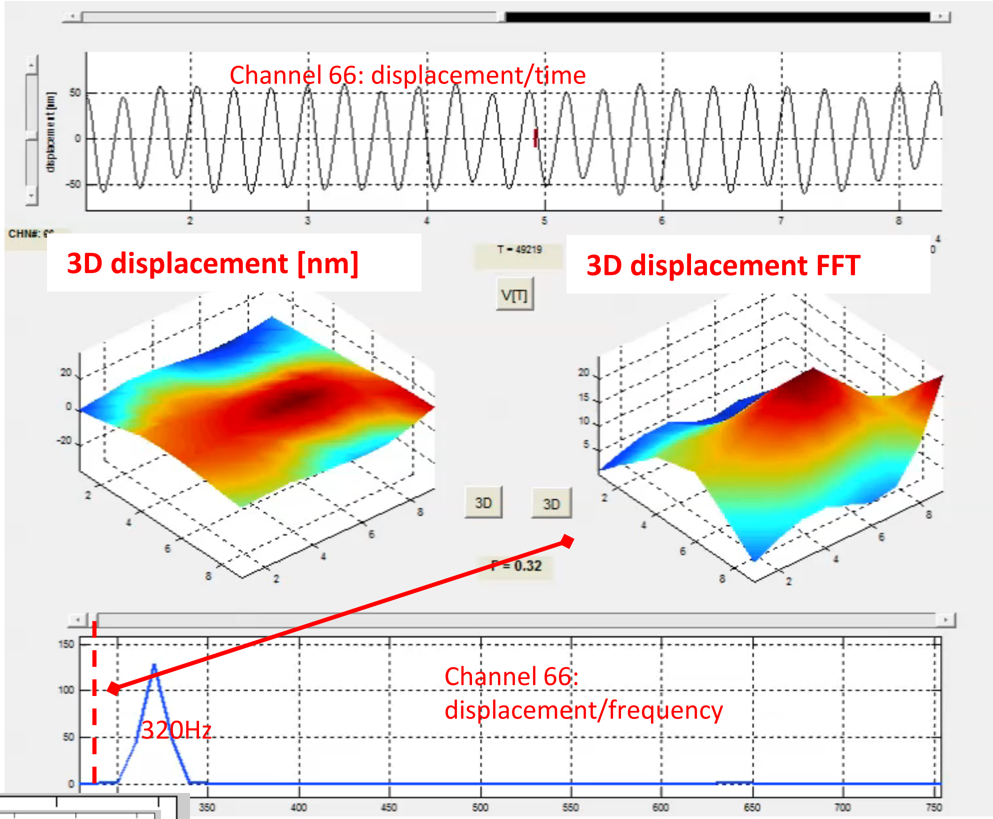
2D/3D Temporal Mode of ARL DM

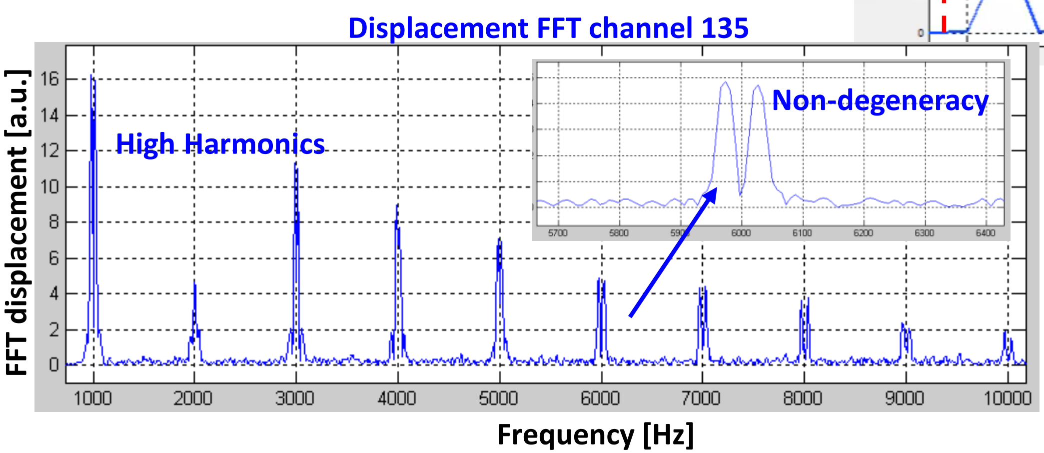
2.2. Damped DM ARL mirror. Central PZT excitation: 300Hz, 17V



2D displacement FFT at 300Hz superimposed on the mirror's image

Animated displacement data

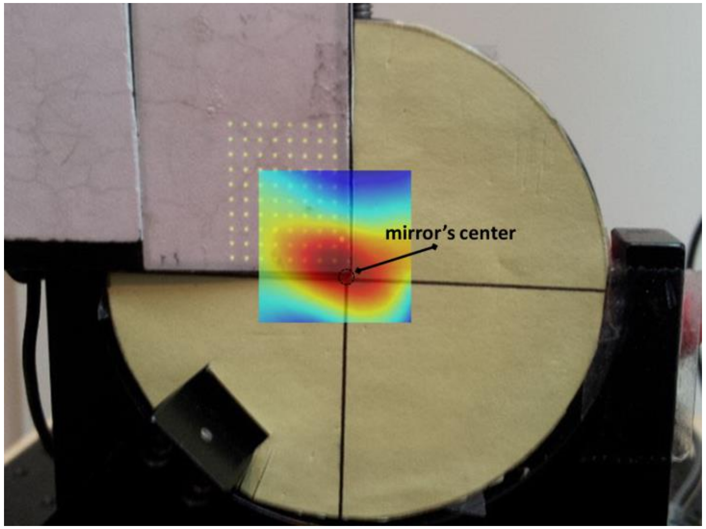




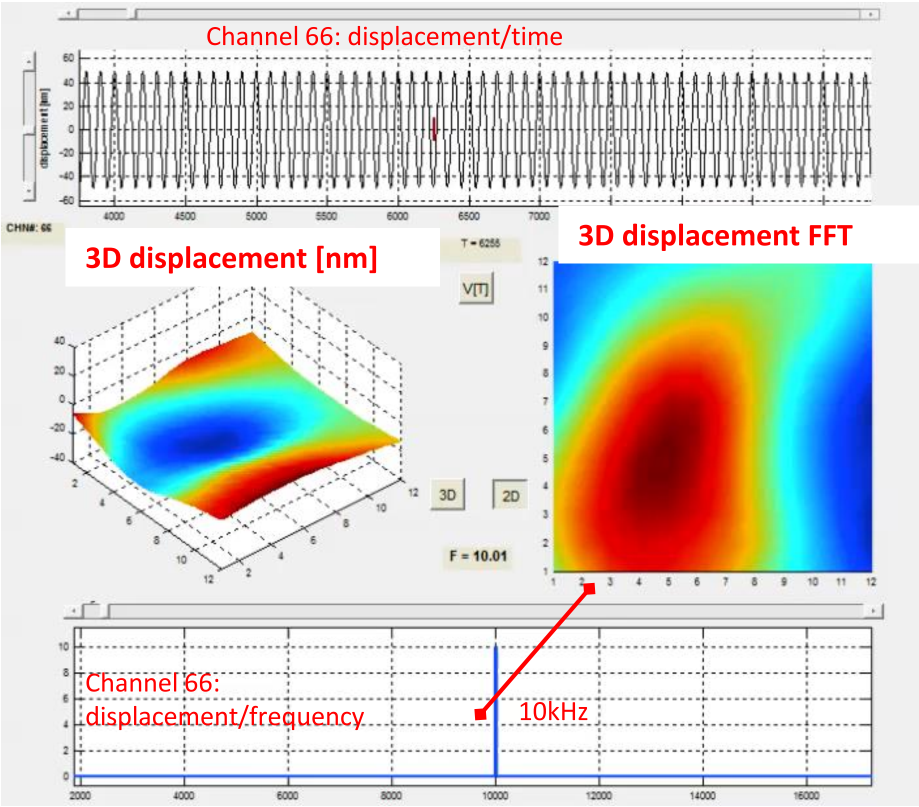
DM_ARL_300Hz_17V_A

2D/3D Temporal Mode of ARL DM

2.3 Damped DM ARL mirror.
PZTs parallel excitation: 10kHz, 10V



2D displacement FFT map at 10kHz superimposed on the mirror's image

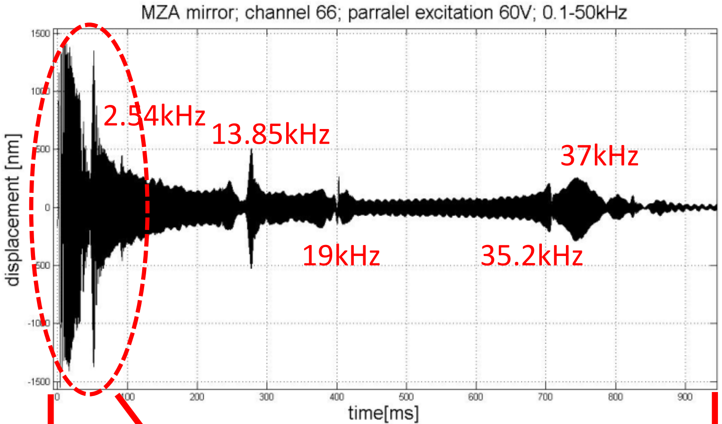


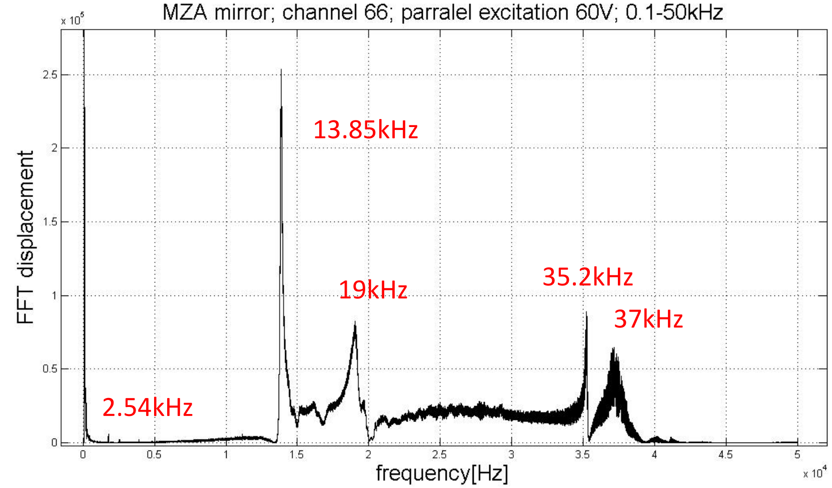
DM_ARL_DAMP_10kHz_LOWVOLT2

2D/3D Temporal Mode: AOS DM 5 Actuators

3.2. MZA mirror. PZTs parallel excitation at 60V, 0.1-50kHz sweep

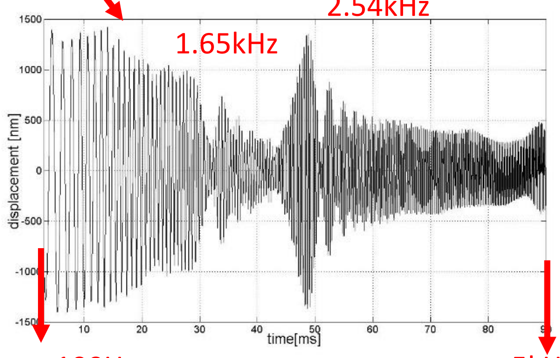
Channel 66: displacement in time and its FFT



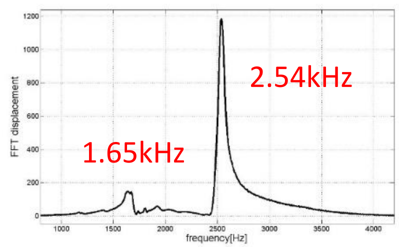


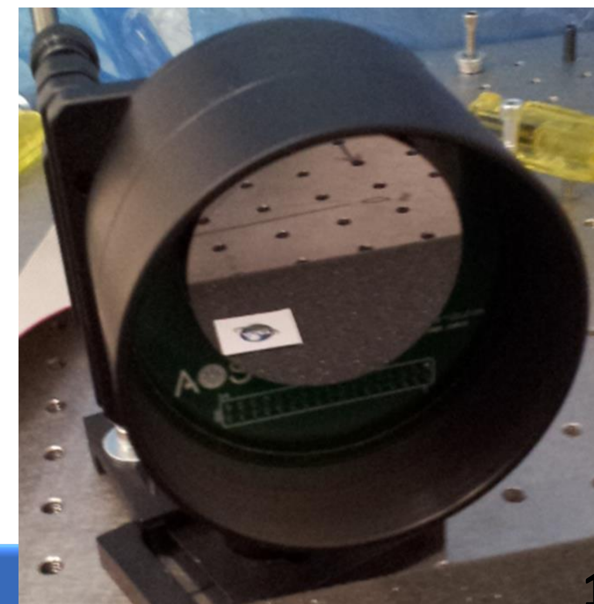
Frequency sweep

100Hz...50kHz



100Hz...5kHz



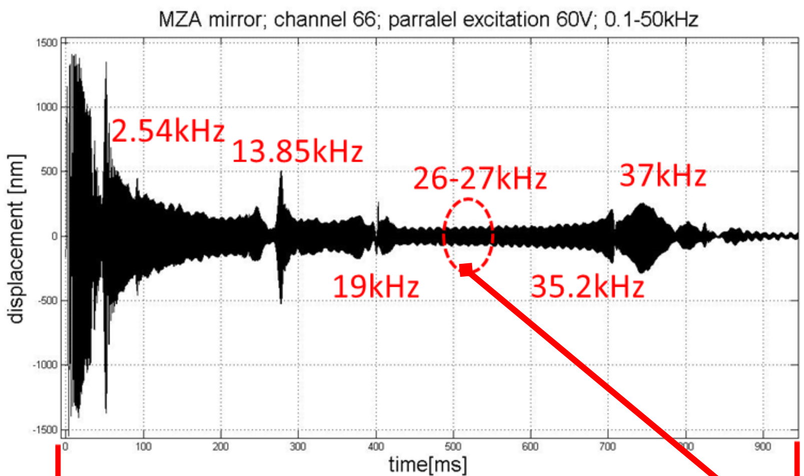


2D/3D Temporal Mode: AOS DM 5 Actuators

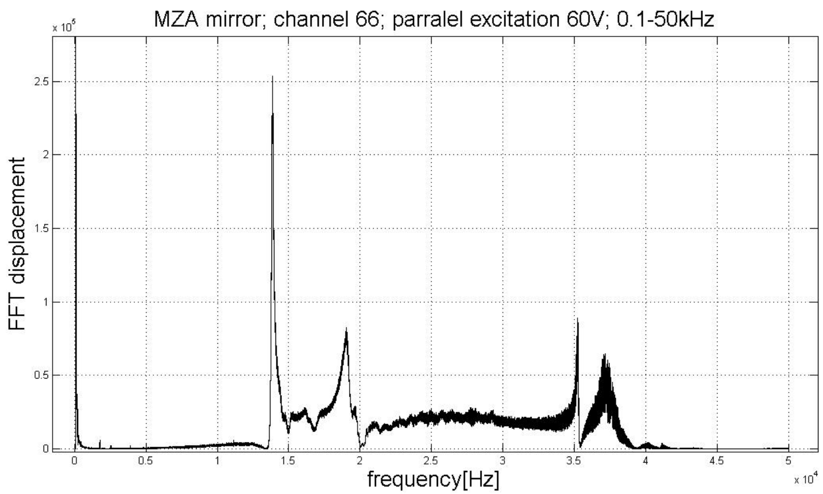
AOS mirror:

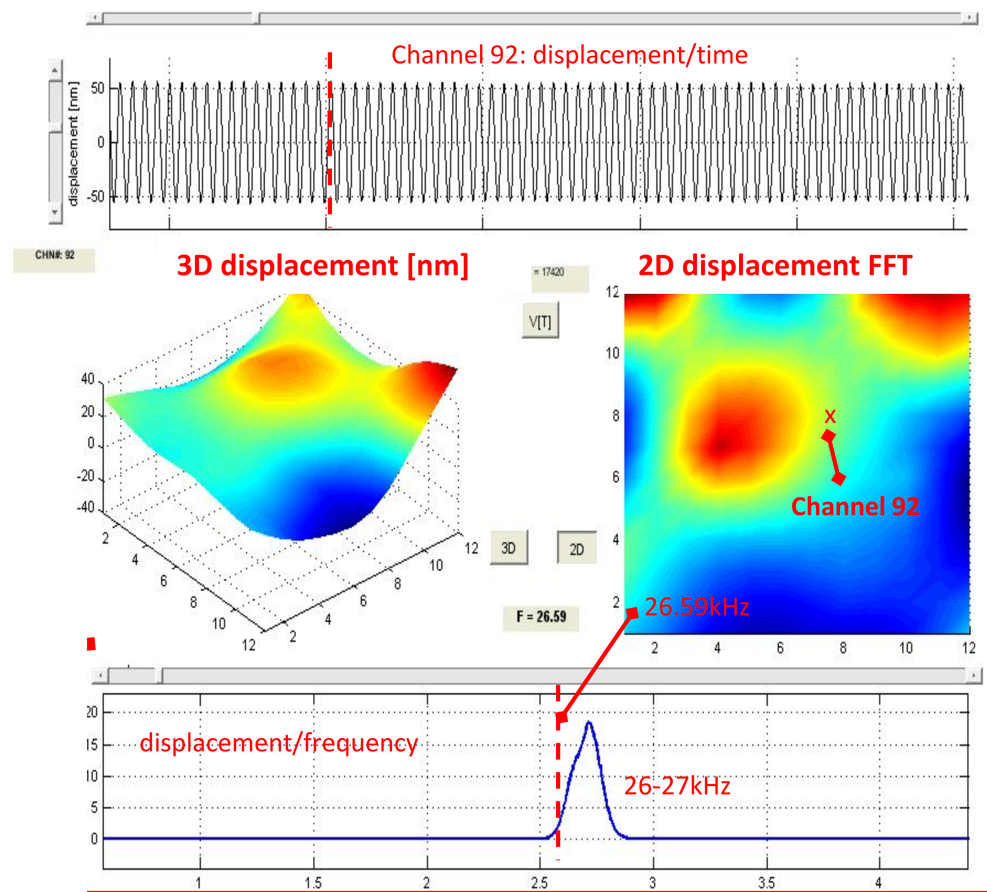
- **PZTs parallel excitation at 10V**
- **15-50kHz sweep frequency excitation**

3D displacement snapshot corresponding to 26.6kHz excitation



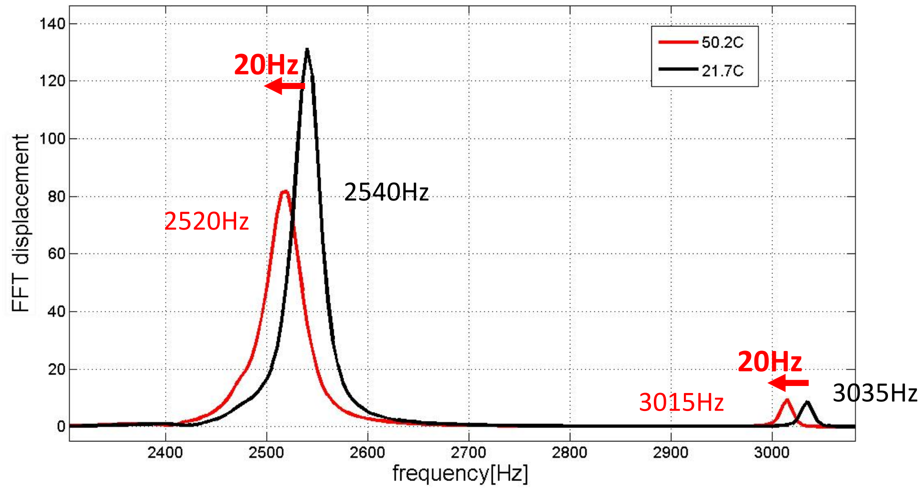
Frequency sweep
100Hz……………………………………………………………50kHz

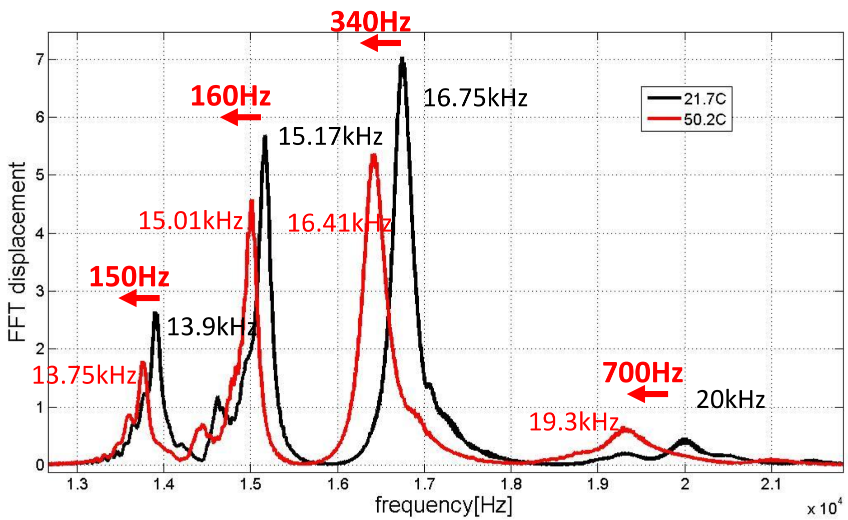




File: MZA_0.1_50kHz_10v_B

3.4. MZA mirror. PZTs parallel excitation at 10V; 15-50kHz sweep frequency excitation; Temperature dependence channel 5





Temperature dependence of channel #5 resonant modes (black curves: 21.7C, red curves: 50.2C). PZTs parallel excitation at 10V: (a) 2-3.1kHz sweep frequency excitation; (b) 13-22kHz sweep frequency excitation.

Conclusions & Future Plans

Future Plans

- FEA modeling of the DMs performance, correlation of the extracted mode shapes/frequencies to the test data
- Flexible system architecture to accommodate DMs in alternative designs and configurations – SM/TM modes
- Data Fusion of SM and TM operation modes
- Refinement of computational models that address the complex interdependent relationship between the mirror working surface, support architecture, and drive modules of the actuators.
- Validation of DM performance with diverse operational parameters
- Explore DM performance on simulated HEL platform: mobile, ship, airborne
- Quest for non-DoD applications and technology consumers

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Program Manager: Mr. Peter A. Morrison
peter.a.morrison@navy.mil

Bimorph DM: Army Research Lab
Dr. Leonid Beresnev
leonid.a.beresnev.civ@mail.mil

Thin plate DM: MZA
Dr. Justin Mansell
Justin.Mansell@mza.com

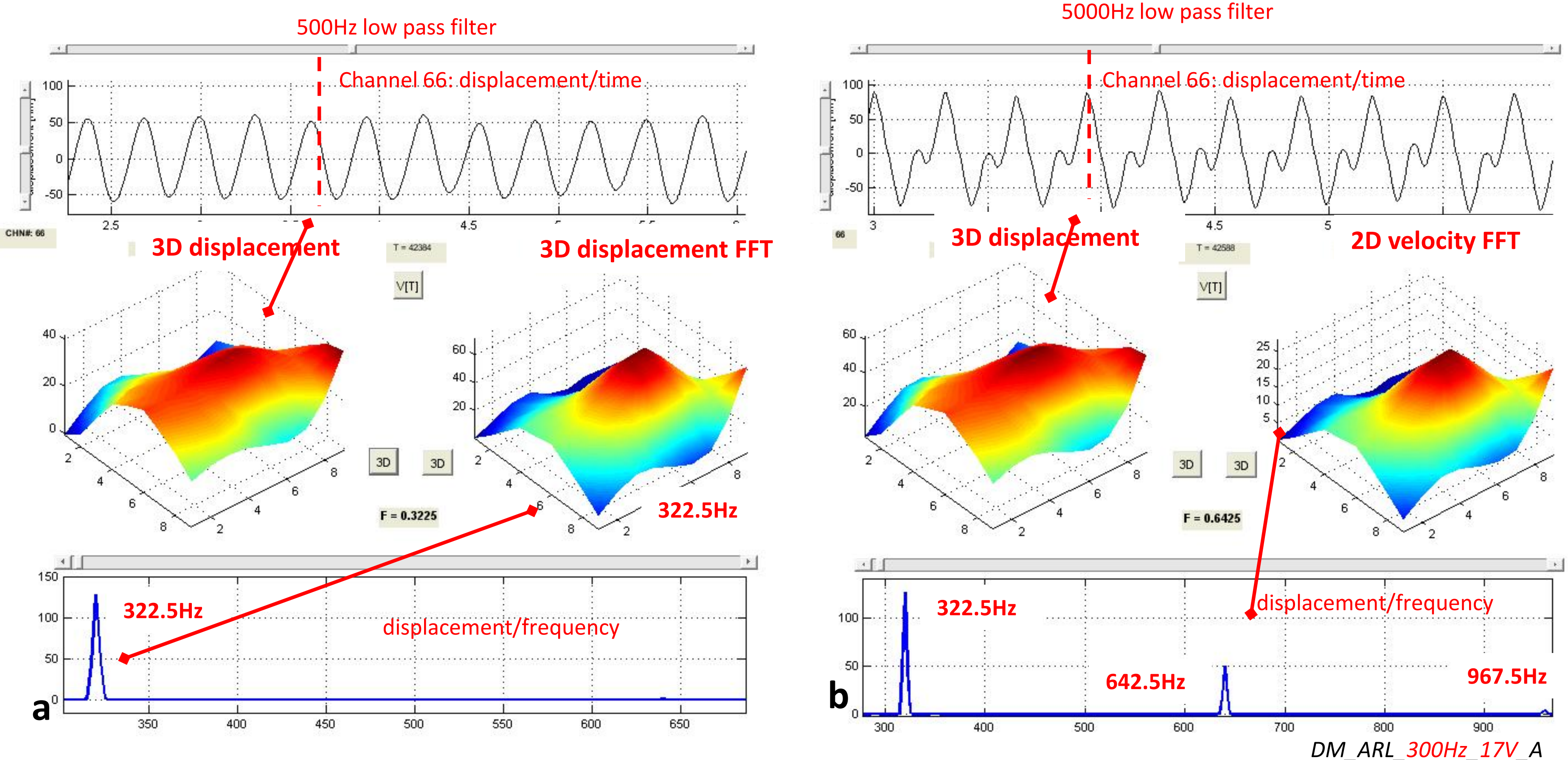
The Large Size Deformable Mirror was offered by JTO

Thank you.

2D/3D Temporal Mode of Bimorph DM

Damped Bimorph DM
Excitation : Central Pin PZT 17 V, 300Hz

Time and Frequency Displacement Data



DM_ARL_300Hz_17V_A