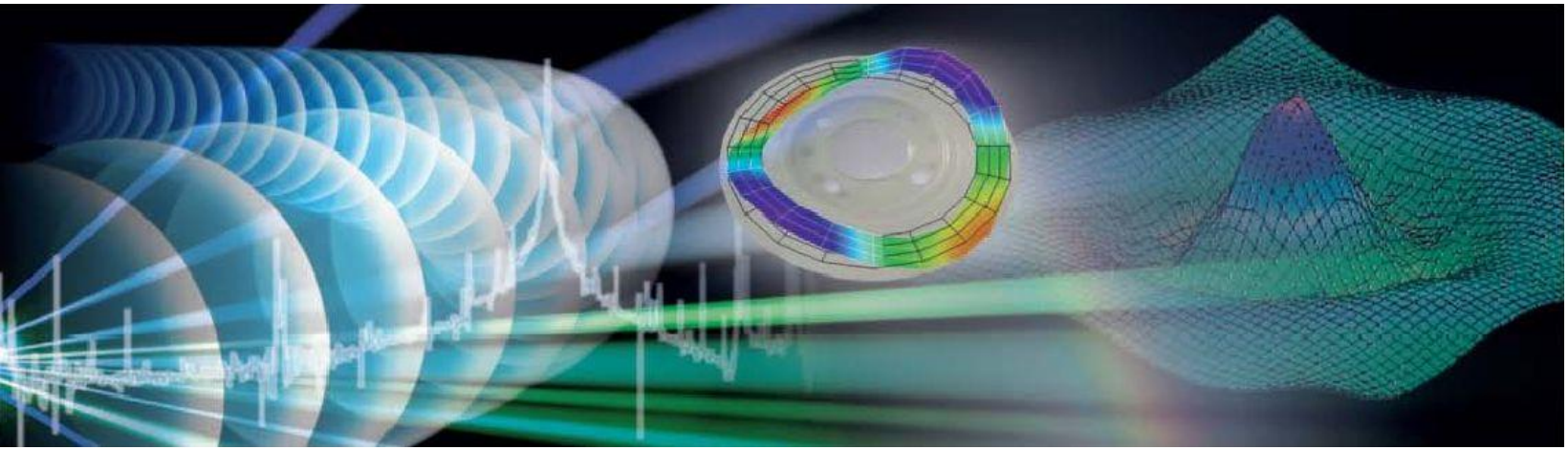
Advancements in Laser Doppler Vibrometry for Ultrasonic Applications



Ultrasonics Industry Symposium

Eric Lawrence, Polytec Inc.

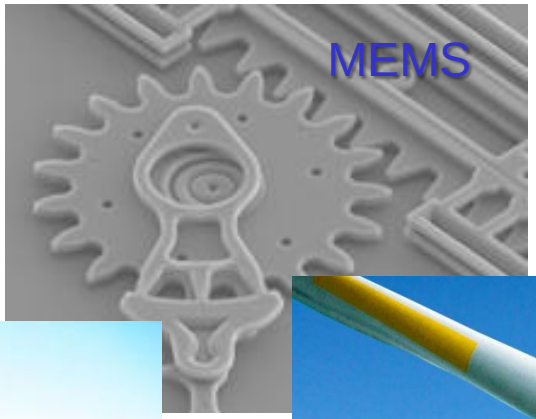
Contents

- Introduction to Laser Vibrometry
- New PSV-500 Scanning Vibrometer
- Application: Ultrasonic Transducer
- Application: Wave Propogation
- Application: Non-Destructive Testing

Tools for Vibration Analysis

Polytec Scanning Vibrometer

Fast, accurate visualization and analysis of structural vibration



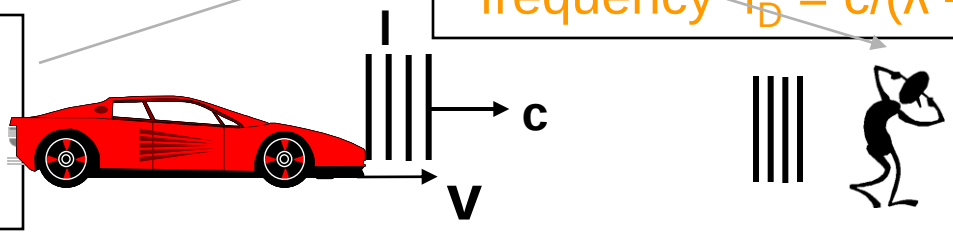
What is Laser Doppler Vibrometry?

Laser **D**oppler **V**ibrometry is a non-contact, "point and shoot" technology that directly measures the vibration of a test object using the Doppler effect.

Analogy: Acoustic Doppler Effect

For car moving at velocity V, the observer hears the frequency $f_D = c/(\lambda - V/f)$.

Sound emitted from stationary car has frequency $f = c/\lambda$



Emitted frequency f

Observed frequency f_n

c: velocity of the sound wave

λ: emitted wavelength

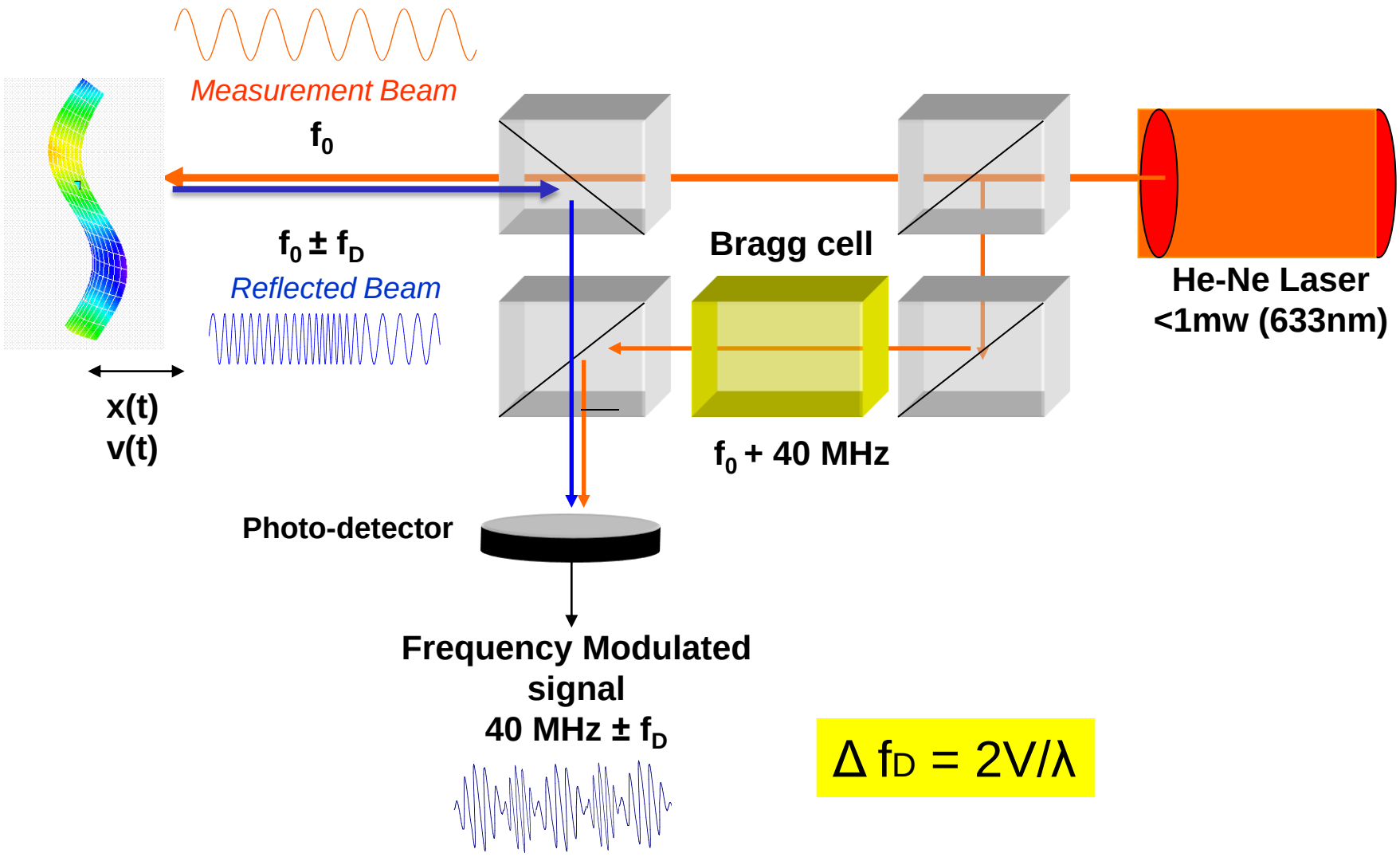
f: emitted frequency

For a vibrometer: $\Delta f_D \propto V$

$\Delta f_D = 2V/\lambda$

The Heterodyne Interferometer

Polytec



$$\Delta f_D = 2V/\lambda$$

Signal Demodulation

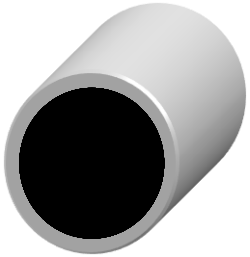
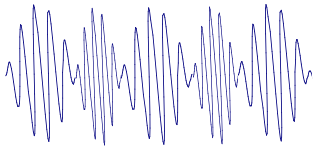


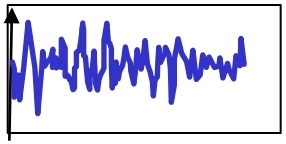
Photo-detector system



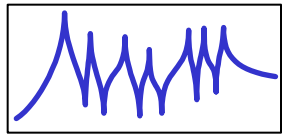
FM Doppler signal

Controller

Voltage ~ Velocity



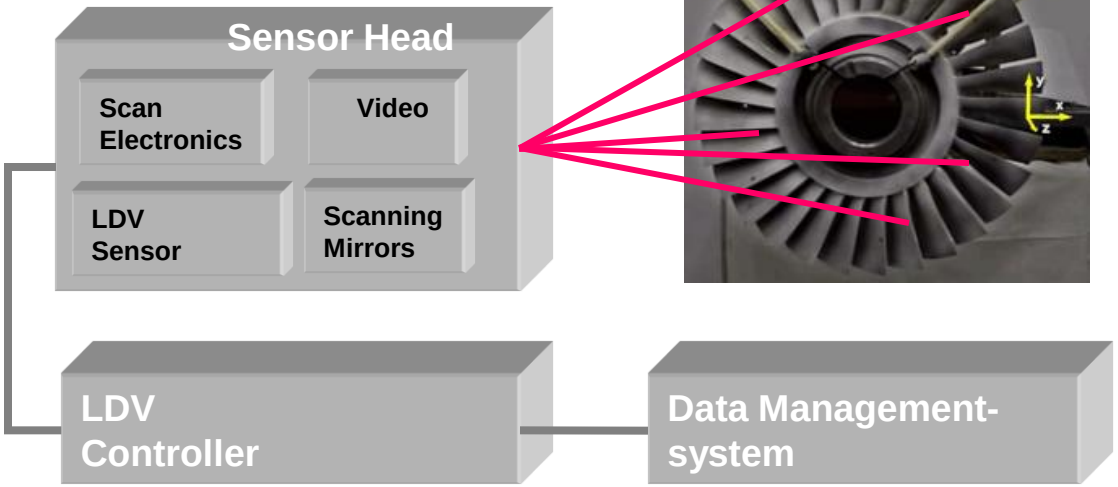
AM electrical signal



FFT Spectrum

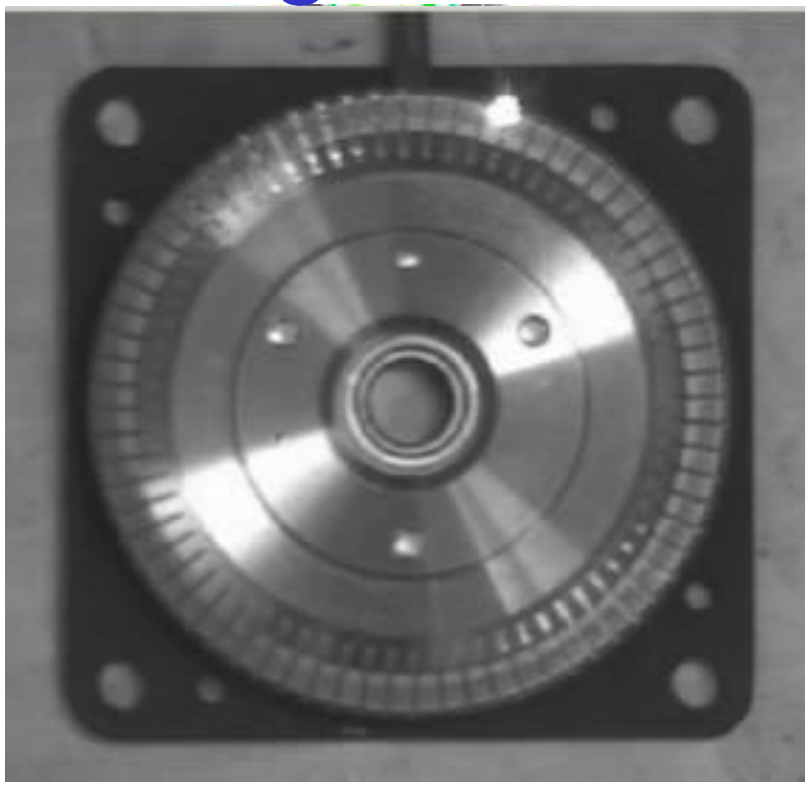
Voltage ~ Displacement

SLDV = Scanning Laser Doppler Vibrometry



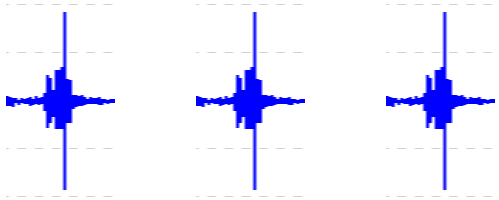
- Up to 250,000 points scanned
- Easy-to-use software for data acquisition, display & manipulation
- Animated data visualization
- Efficient interfaces for modal analysis or FEM validation
- Geometry file imported or measured

Scanning Vibrometer



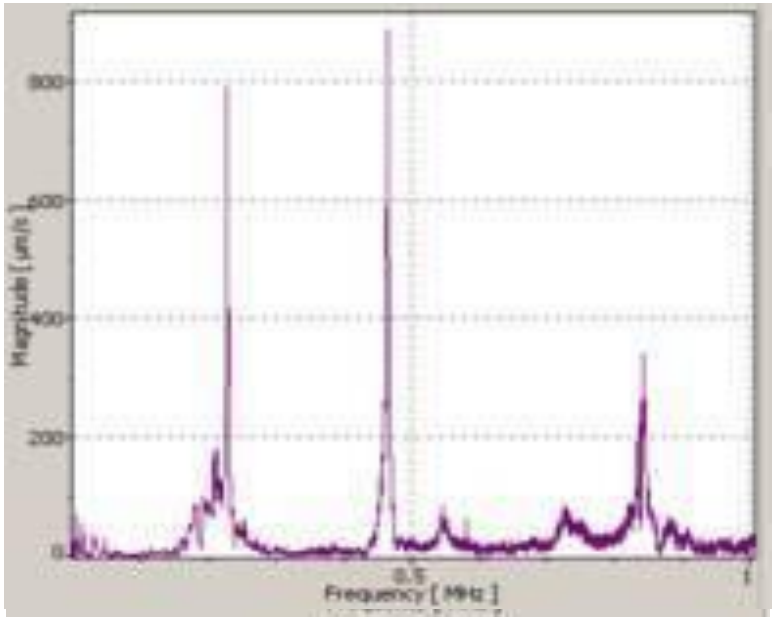
piezo motor

Vibration Time Signal



sequential measurement at all points.
Excitation for all points

Vibration Spectrum



Unique Features Laser Vibrometer

- **Real Time Measurement**: fast signal-based measurements from broadband excitation, can measure transient response
- **Scan Measurements:** 3D animations allow full-field visualization
- **High Resolution:** displacement resolution down to *picometer*
- **High lateral resolution:** laser spot focused down to 700 nm
- **High frequency bandwidth**: flat frequency response up to 1.2 GHz
- **High accuracy:** Doppler technique highly accurate and linear
- **Wide Dynamic Range:** from 0.02 μm/s to 30m/s
- **3D Measurement:** coupling of longitudinal/ transverse modes
- **Can do difficult measurements** on range of materials, under required environmental conditions, i.e. thru glass into a vacuum chamber

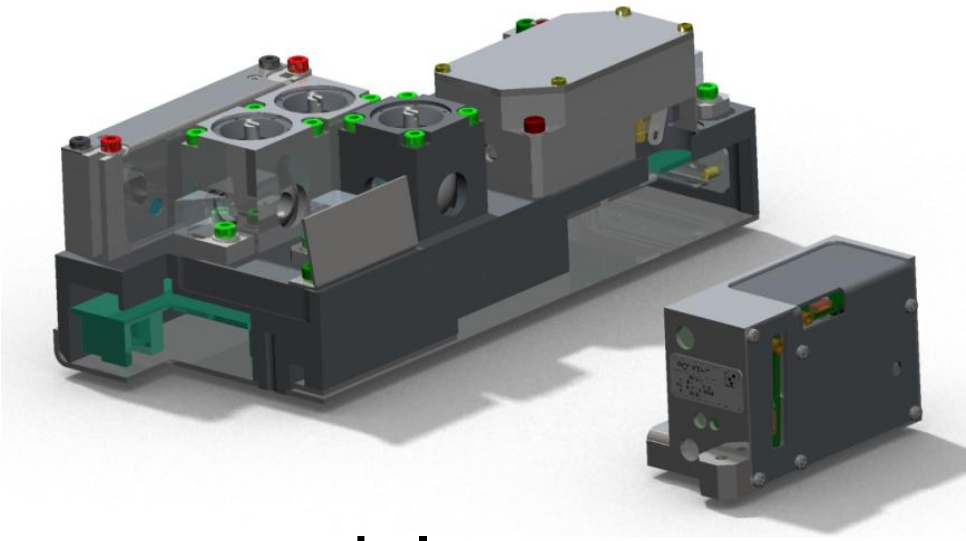
The New Polytec Scanning Vibrometer PSV-500

Features:

- High Resolution Digital Decoding
- High Spatial Resolution –HD Digital Camera
- 3D Version including Geometry Measurement

The Interferometer

- Determines
  - Optical sensitivity
  - Overall size
  - Ease of maintenance

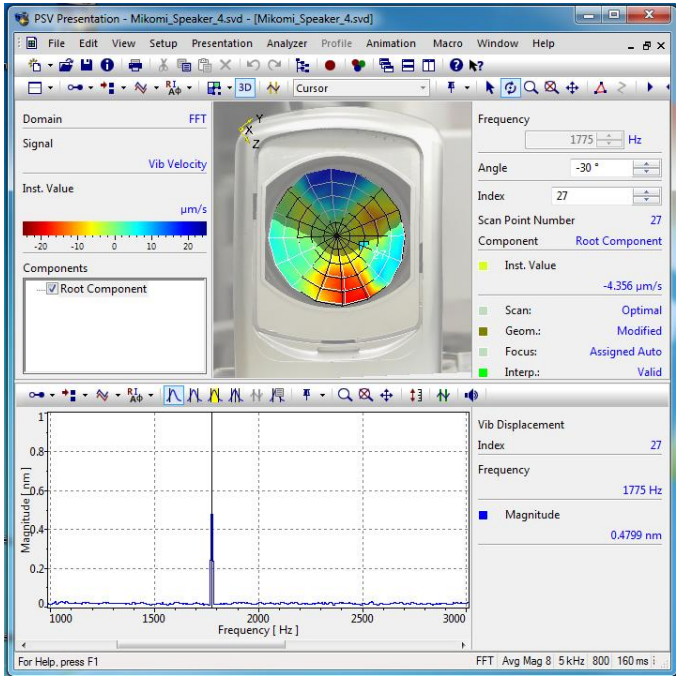


- Miniaturized interferometer module
  - 80% less volume *and* better optical properties

Coherence Optimizer for Stabilization of laser frequency

Digital Broadband Decoder

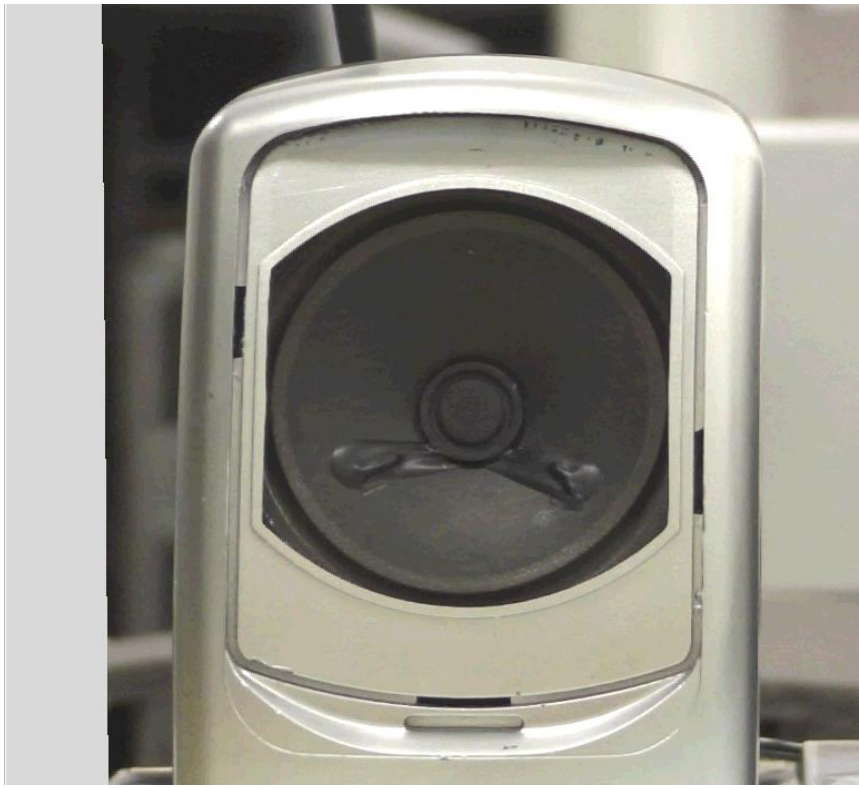
- Decoding of the high-frequency interferometer signal
- 13 measuring ranges with
  - 1 mm/s – 10m/s
  - Resolution better than 10 nm/s/√Hz



VibroLink* Ethernet Data Transmission

Lossless data transmission / low noise for all vibrometers and reference channels

HD camera

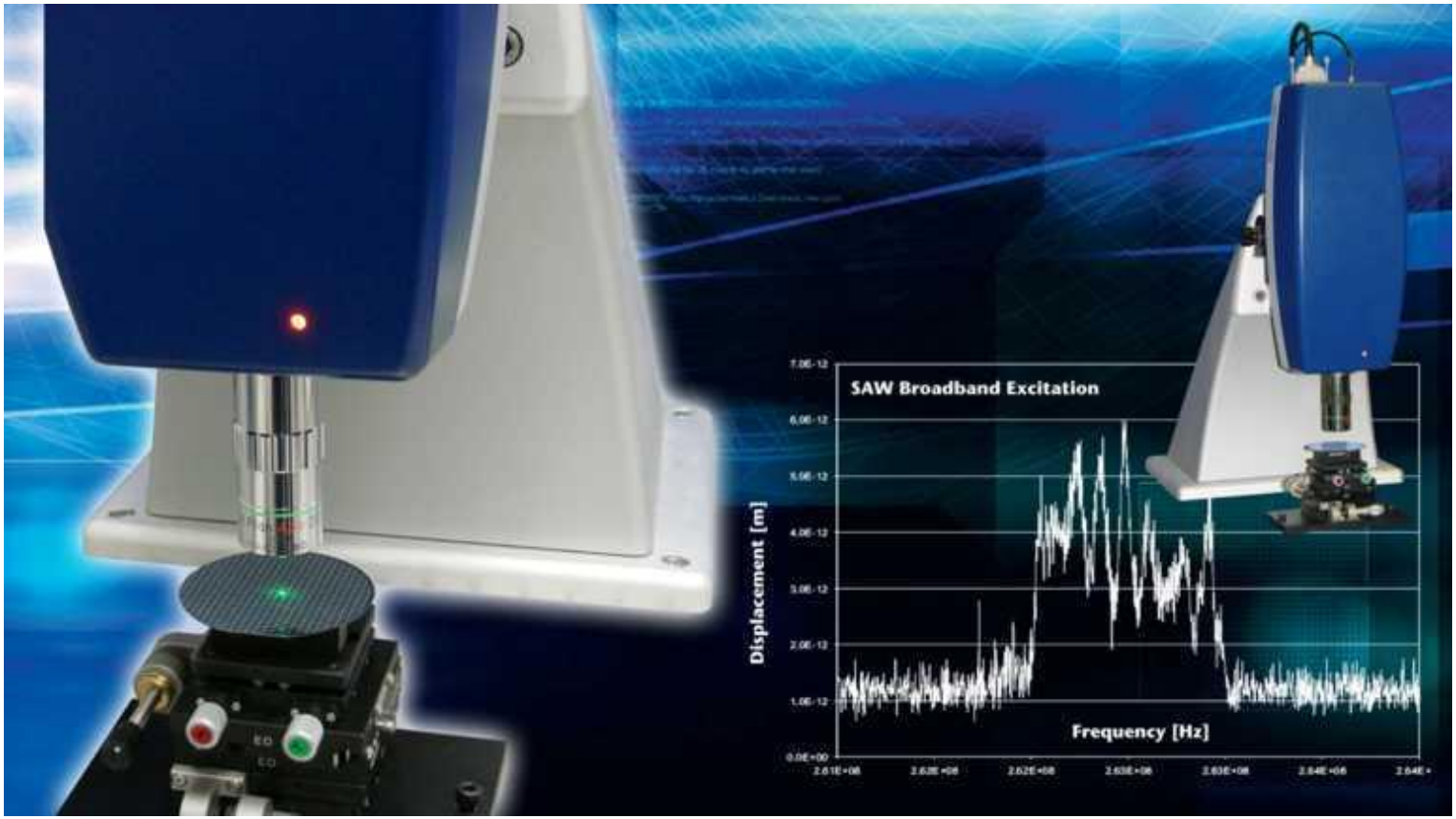


- 4x higher resolution
- 16:9 aspect ratio
  - Adapted to extended scan angle
- Allows high-precision remote alignment
- Impressive visualization
- Lossless data transmission thanks to

Ultrasonic Applications

- PSV-500-M Ultrasonic
  - 2 MHz vibrometer bandwidth
    - Digital decoding, analog data acquisition
    - 13 measuring ranges
  - PSV-500-3D-M for 3D measurements
  - Up to 8 reference channels
  - Signal generator with up to 2 MHz
  - Geometry Scan Unit optional

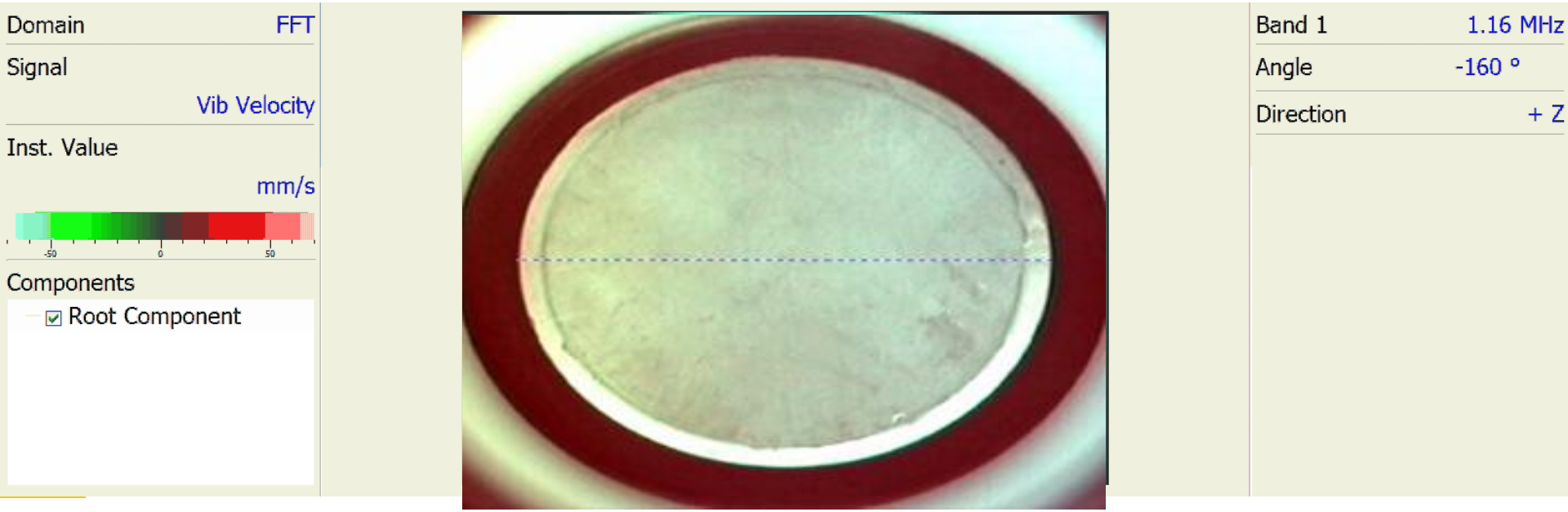
UHF-120 Ultra High Frequency Vibrometer



Application: Ultrasonic Transducers

Example: Scan Measurement of Piezo Transducer used for Ultrasound Therapy

Frequency 1.16 MHz, 50 mm Diameter



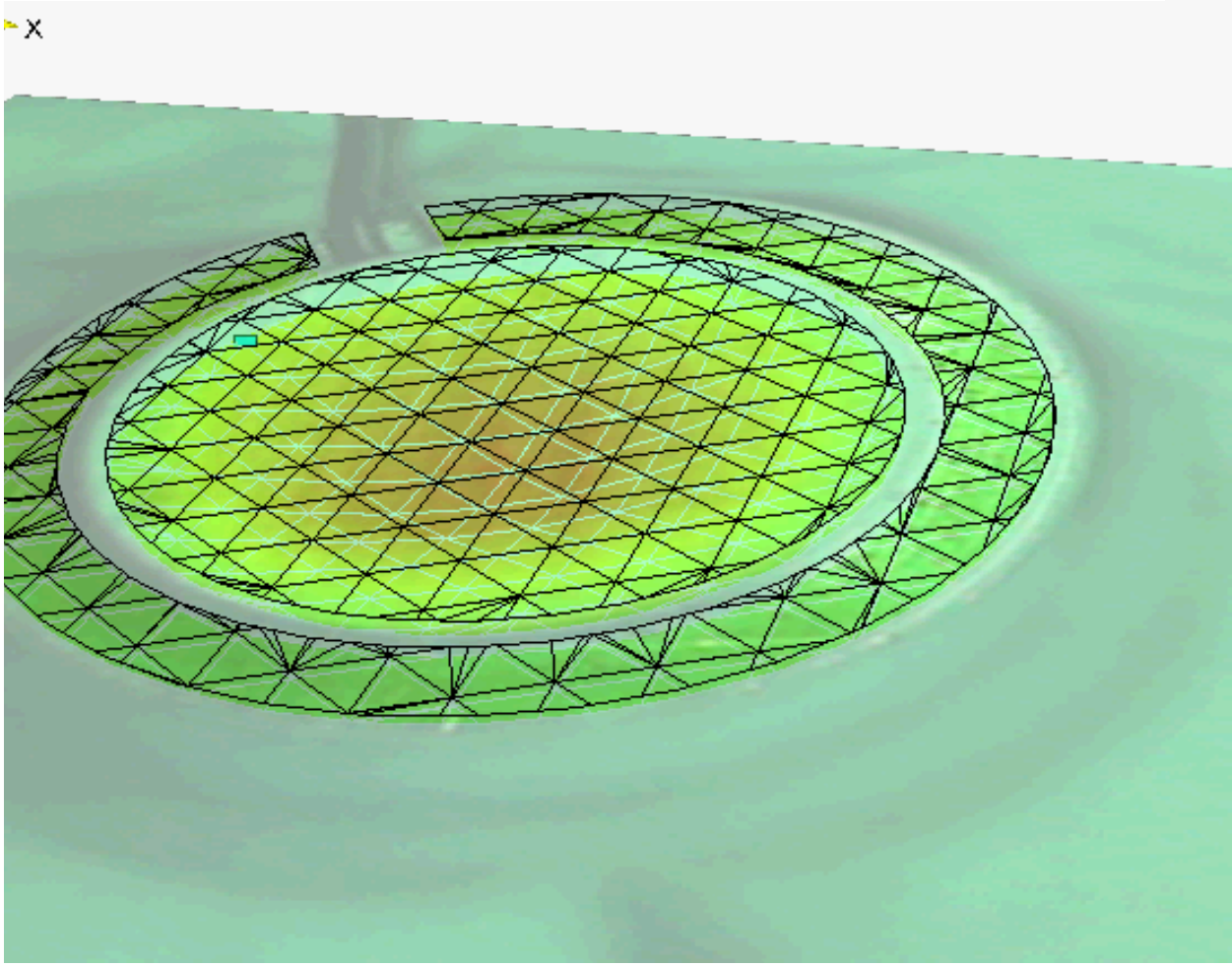
Domain

Ultrasound Transducer used for Ultrasonic Flow Meter

Determine uniformity of deflection shape profile along orthogonal axes

Testing to determine optimum mounting (material, edge shape, bonding of glue)

Revision of FE Modeling based on results.

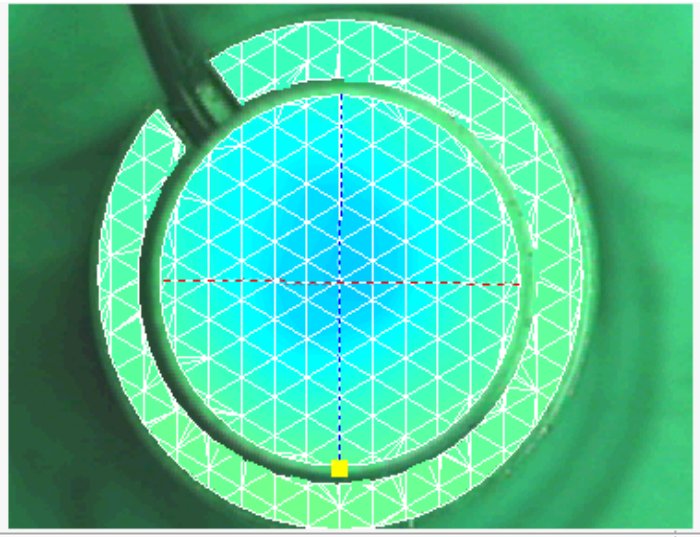


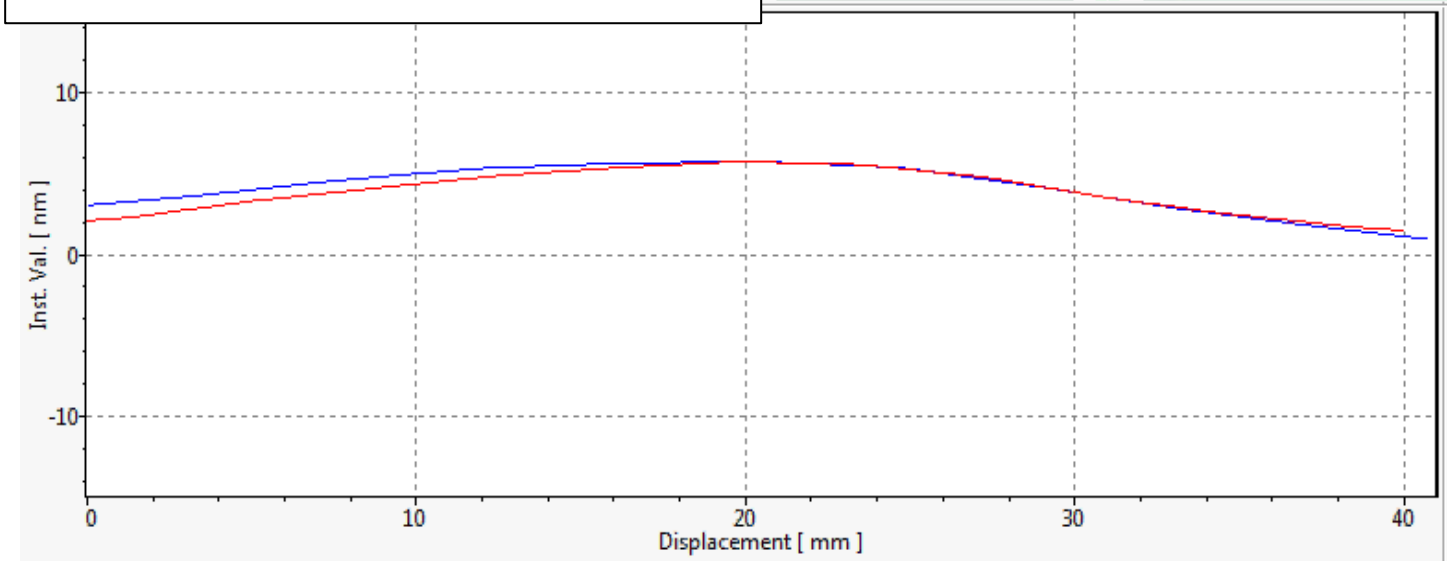
•Application: Ultrasonic Transducer

Profile Measurement along Orthogonal Axes

Mounting causes slight variations:

X profile vs. Y profile





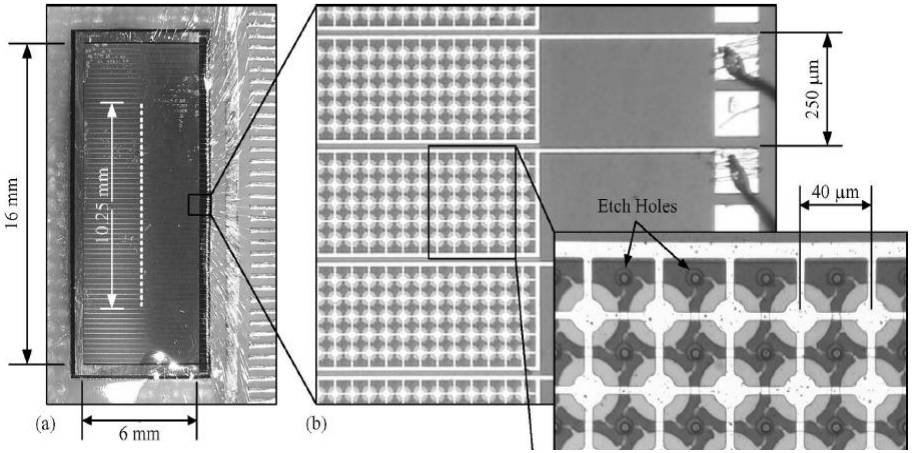
•Application: CMUT Transducer

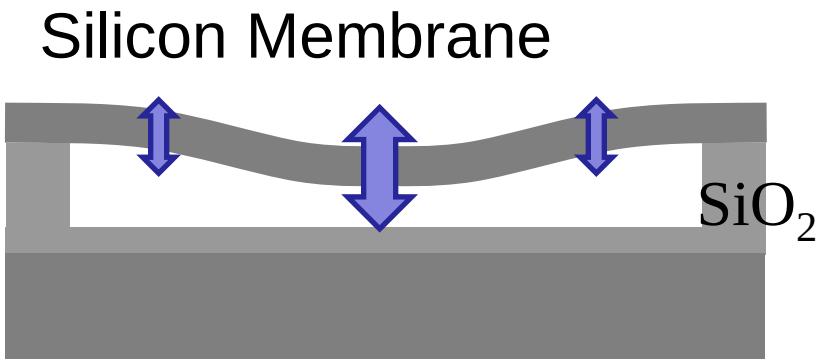
KHURI-YAKUB ULTRASONICS GROUP

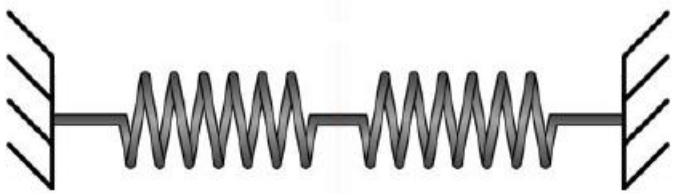
Characterization of Capacitive Micromachined Ultrasonic Transducers

Micro-fabricated device to generate and receive ultrasound

Demonstrated frequency range: 10 kHz to 100 MHz

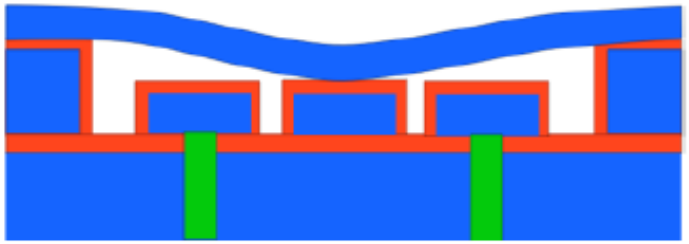






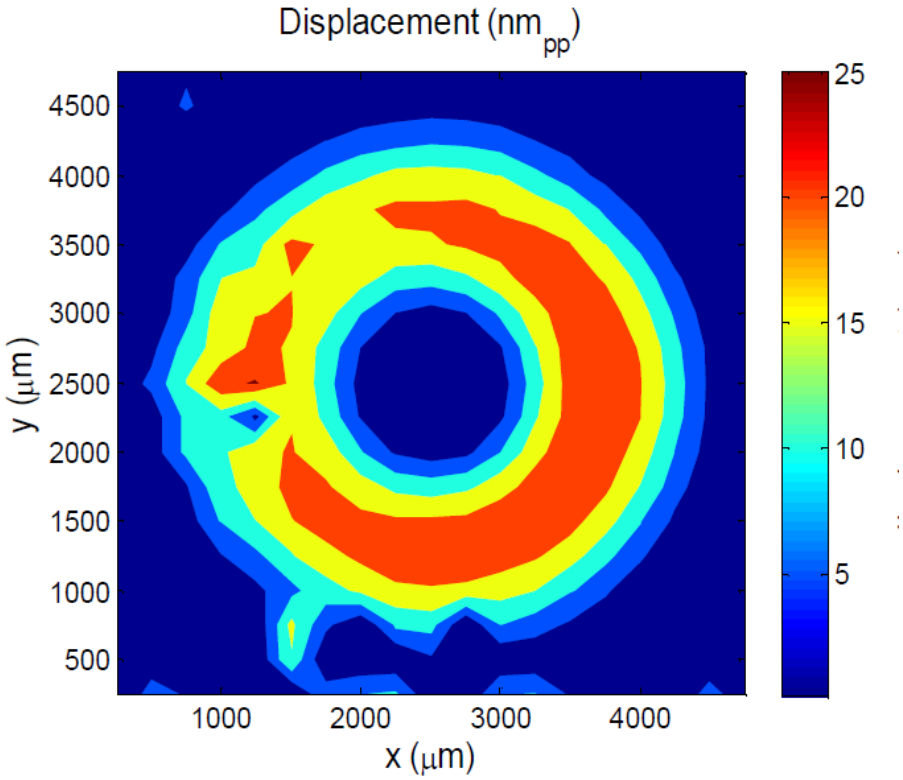
k(t), m(t)

Dynamic Characterization of CMUT Designs

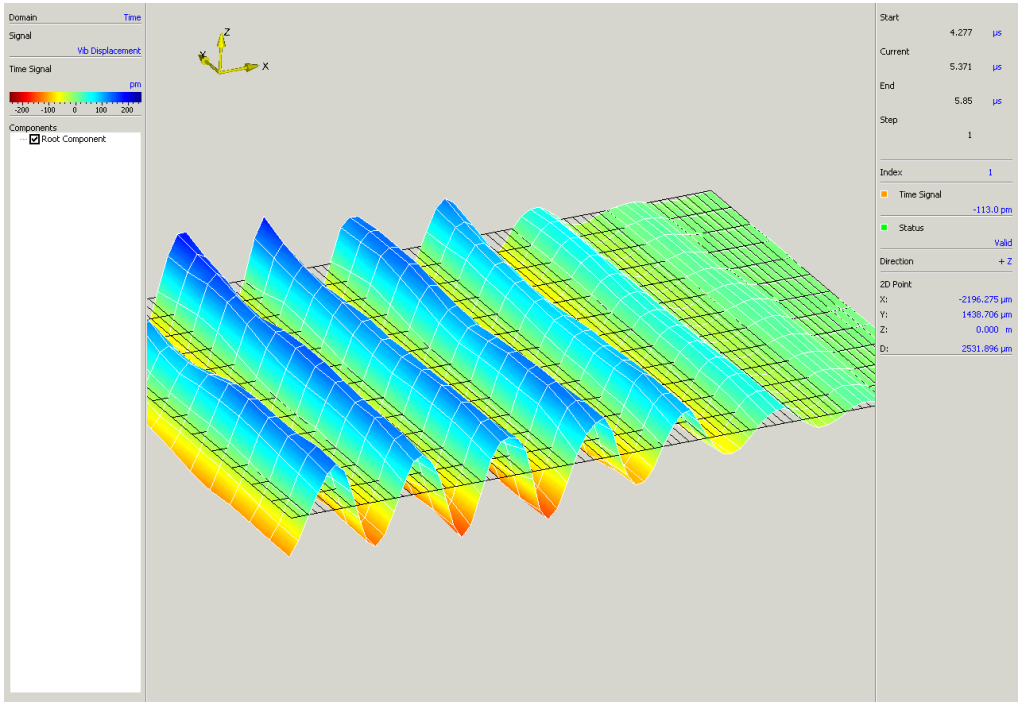


Circular Cell with Permanently Collapsed Center

First mode at 75 KHz,
25 nm pk-pk displacement

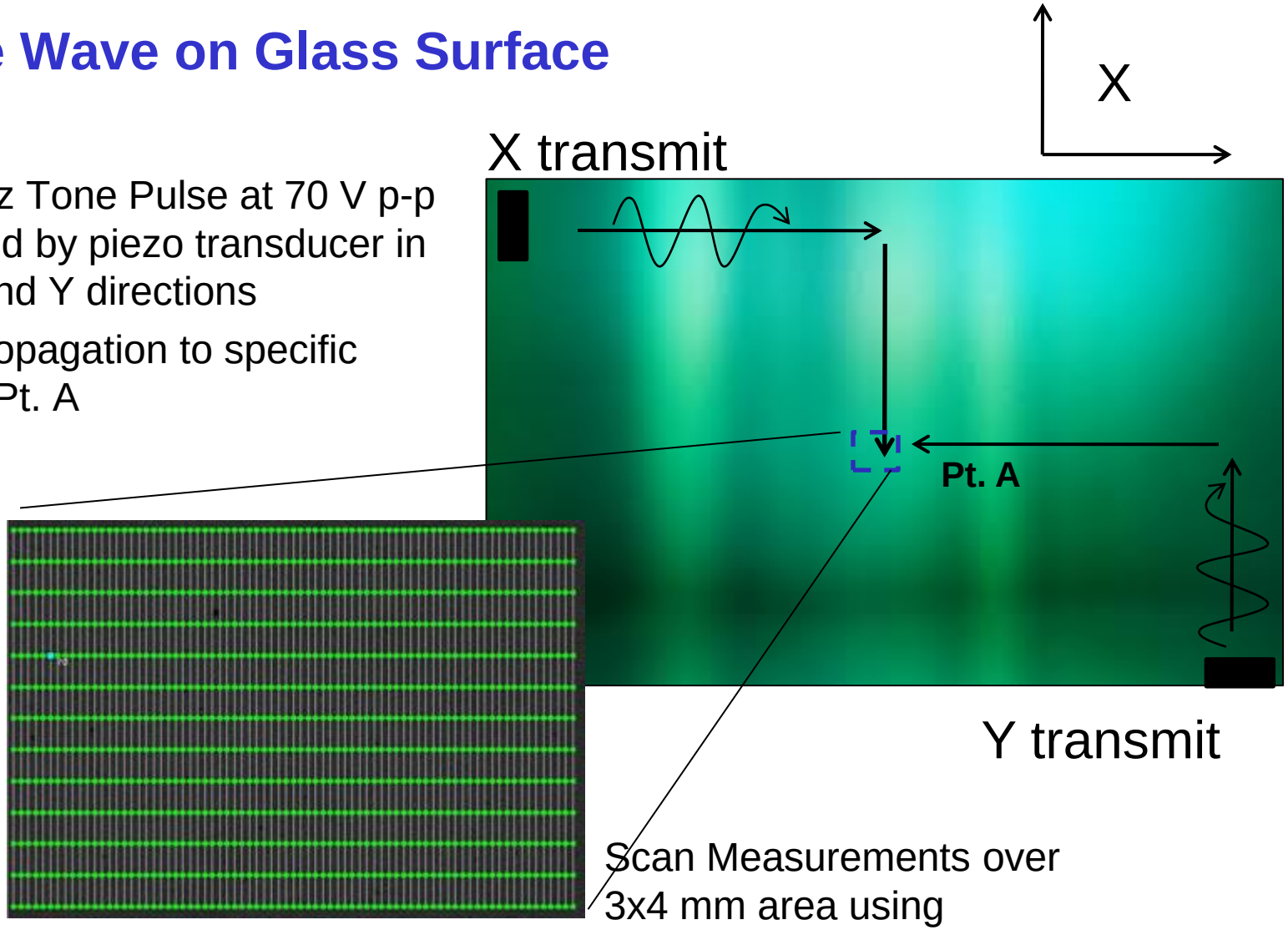


Wave Propagation Measurements



Surface Wave on Glass Surface

- 5.51 MHz Tone Pulse at 70 V p-p generated by piezo transducer in both X and Y directions
- Wave propagation to specific location Pt. A

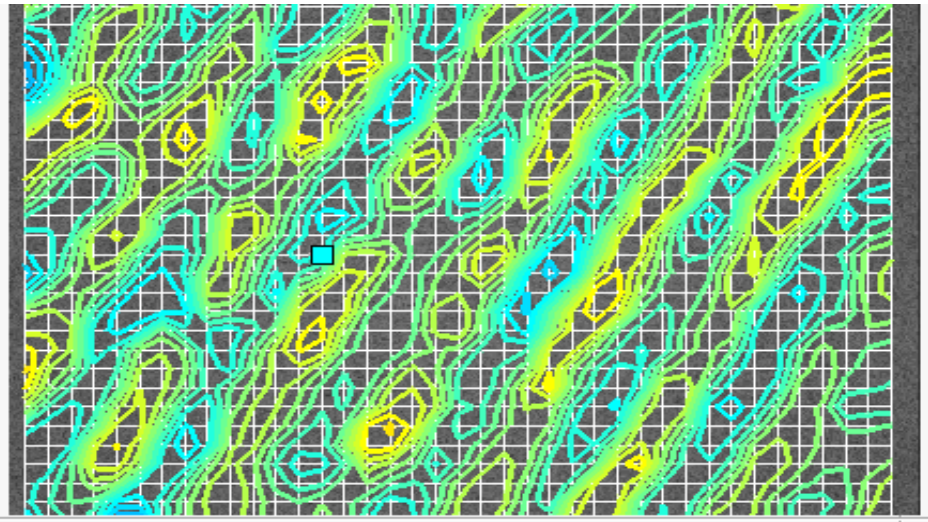


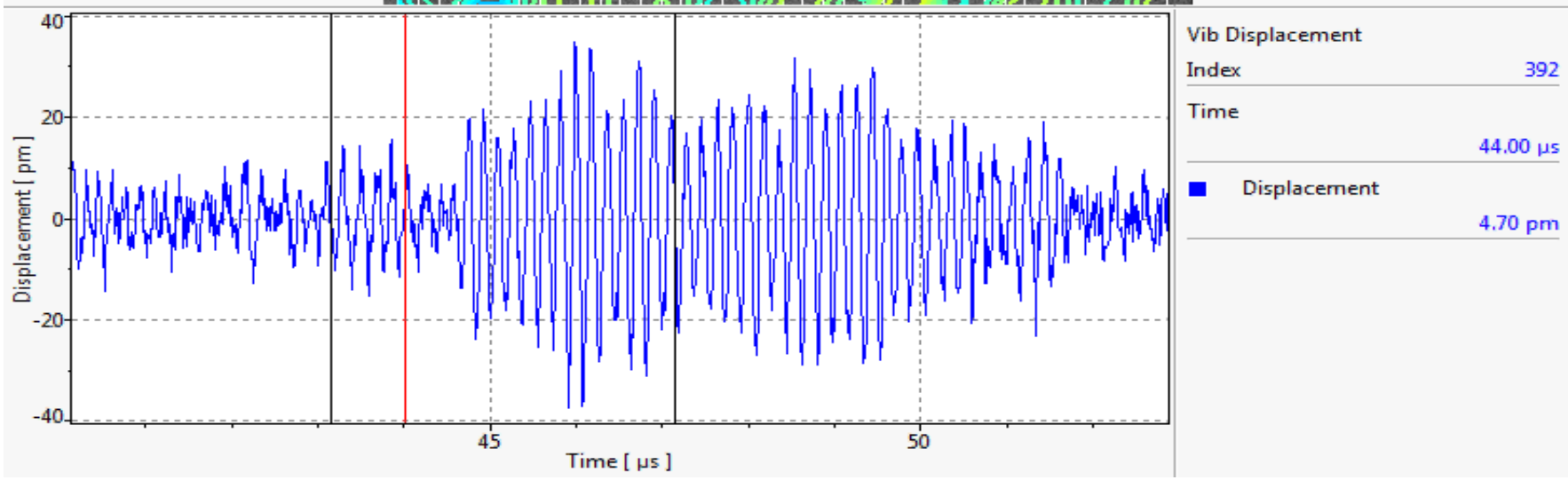
Scan Measurements over 3x4 mm area using

1000 measurement points

Surface Wave on Glass Surface

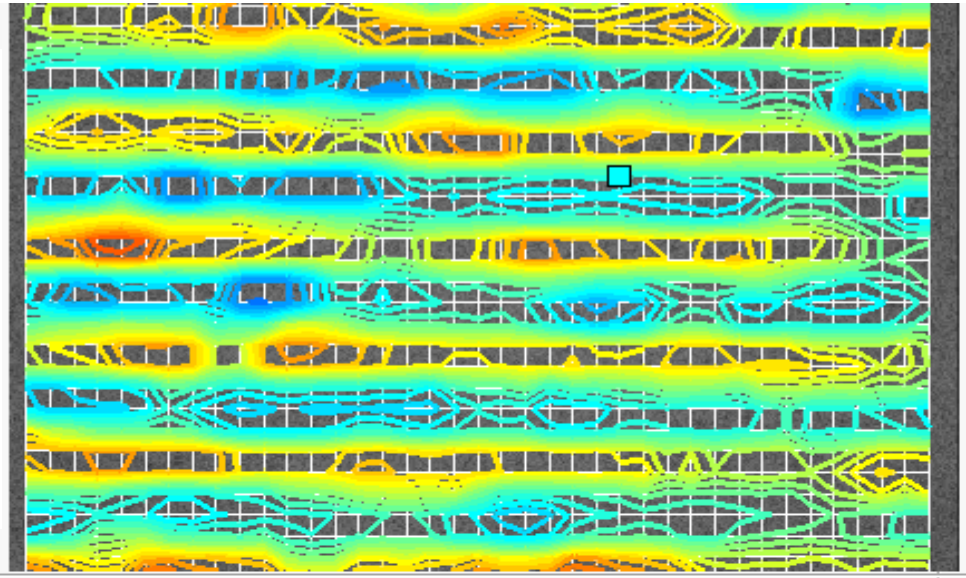
Arrival of Horizontal Wave

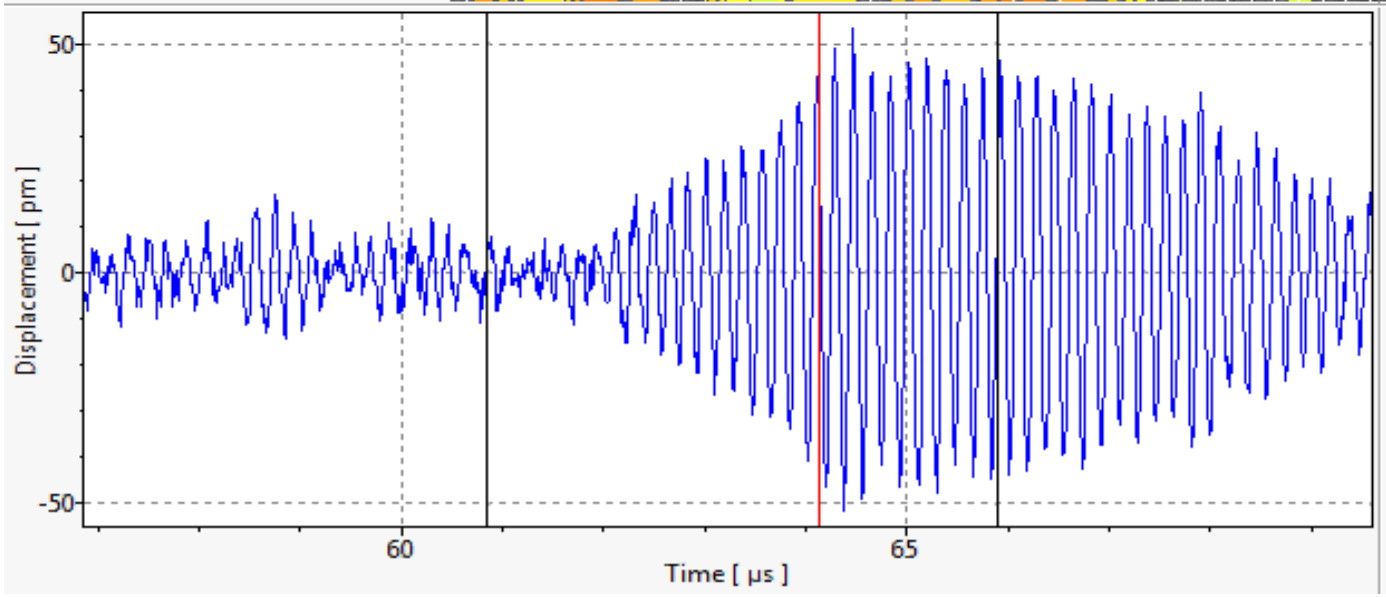




•Application: Wave Propagation

Arrival of Vertical Wave (18 ms later)





Vib Displacement

Index 735

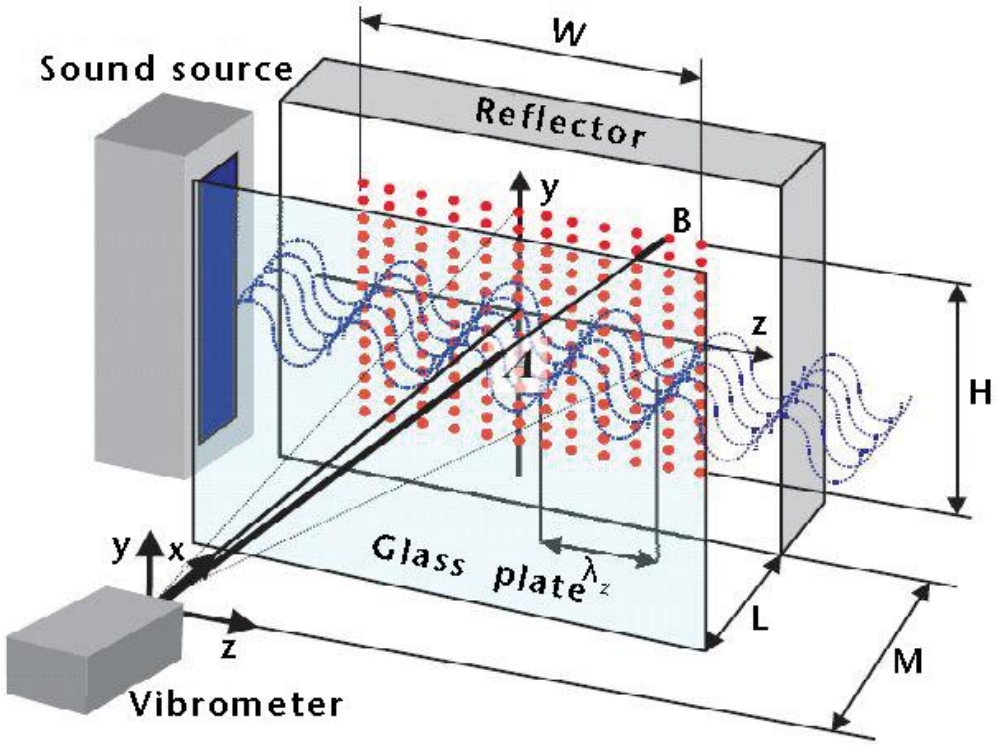
Time 64.14 µs

Displacement 23.16 pm

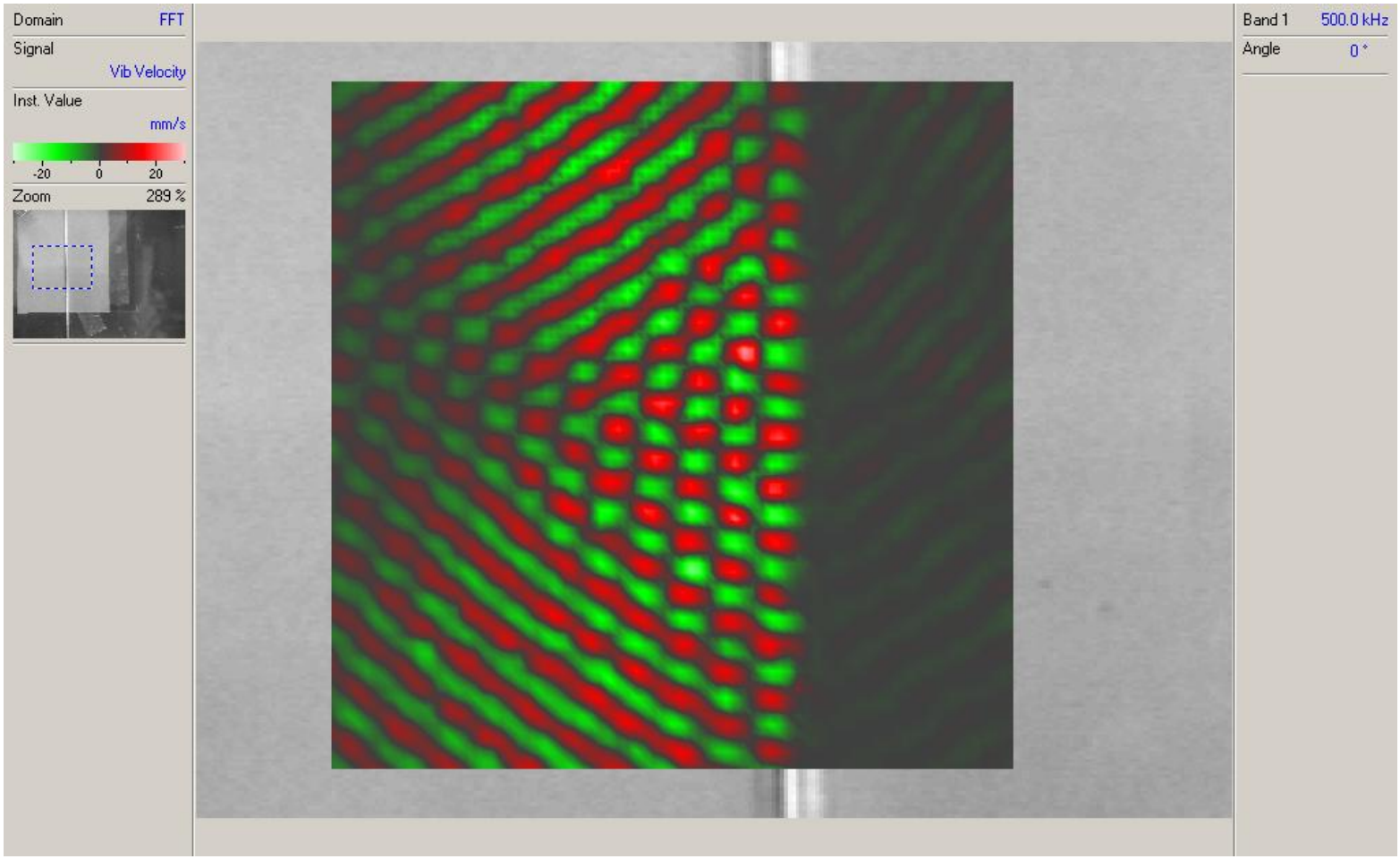
Refracto-Vibrometry

Measurement of Waves Propagated in Air

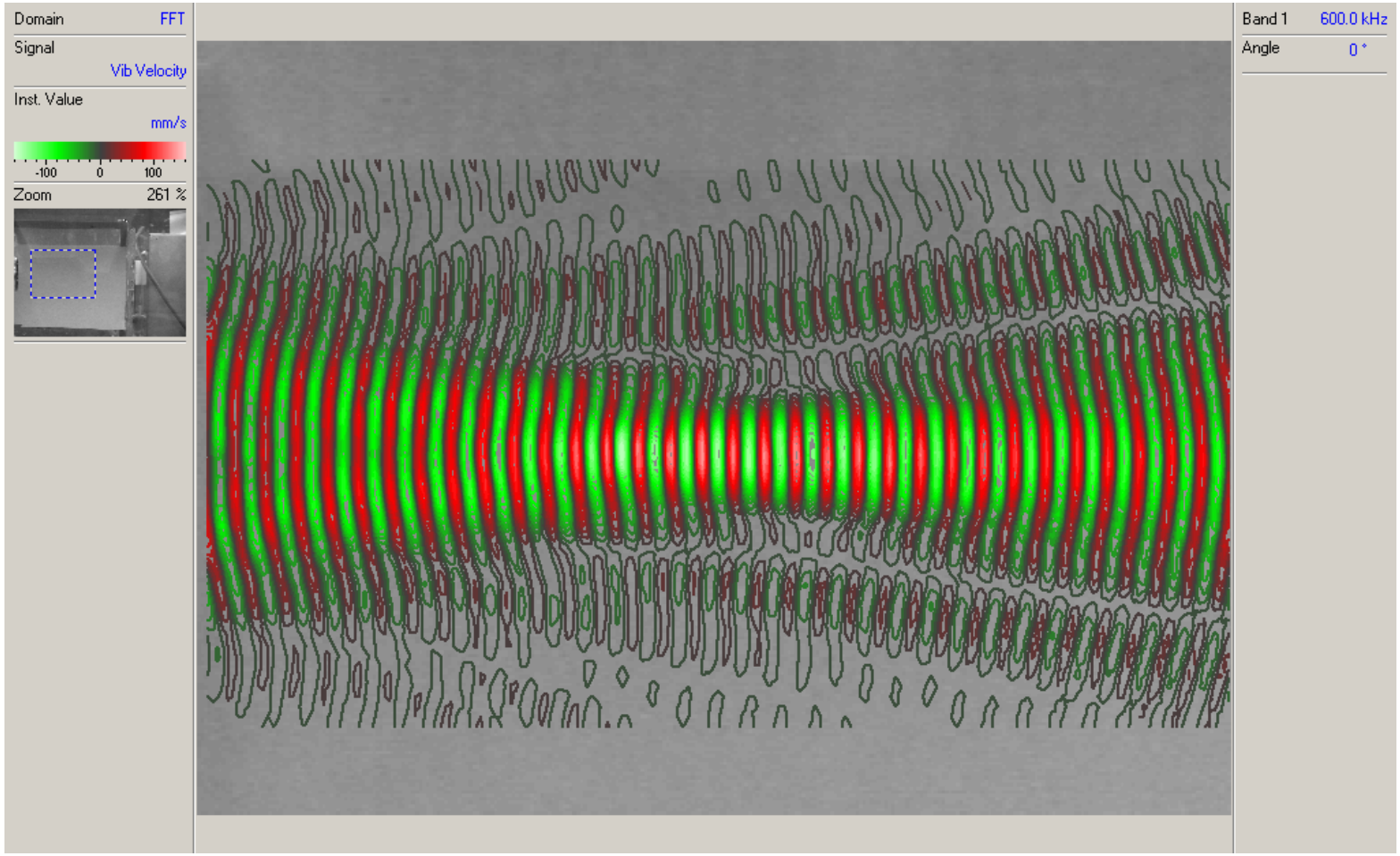
- Measurement of wave distribution in air (Radiation Pattern)
- Laser beam transmits through propagating ultrasonic wave and is reflected back
- Pressure changes from wave results in fluctuation of optical refractive index
- Velocity distribution mapped out and displayed as a time animation
- Every point is an integration of the sound distribution along path of laser beam



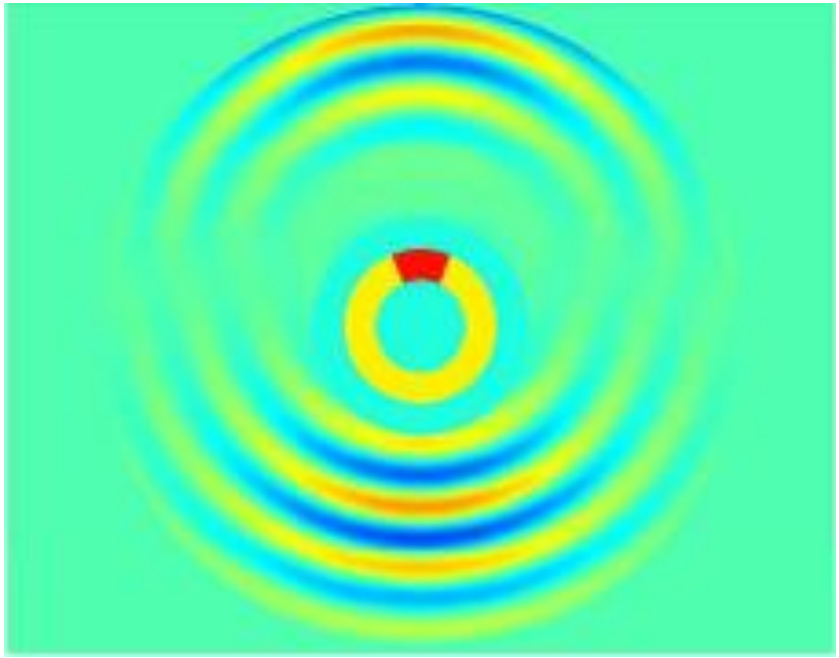
Refracto-Vibrometry



Refracto-Vibrometry



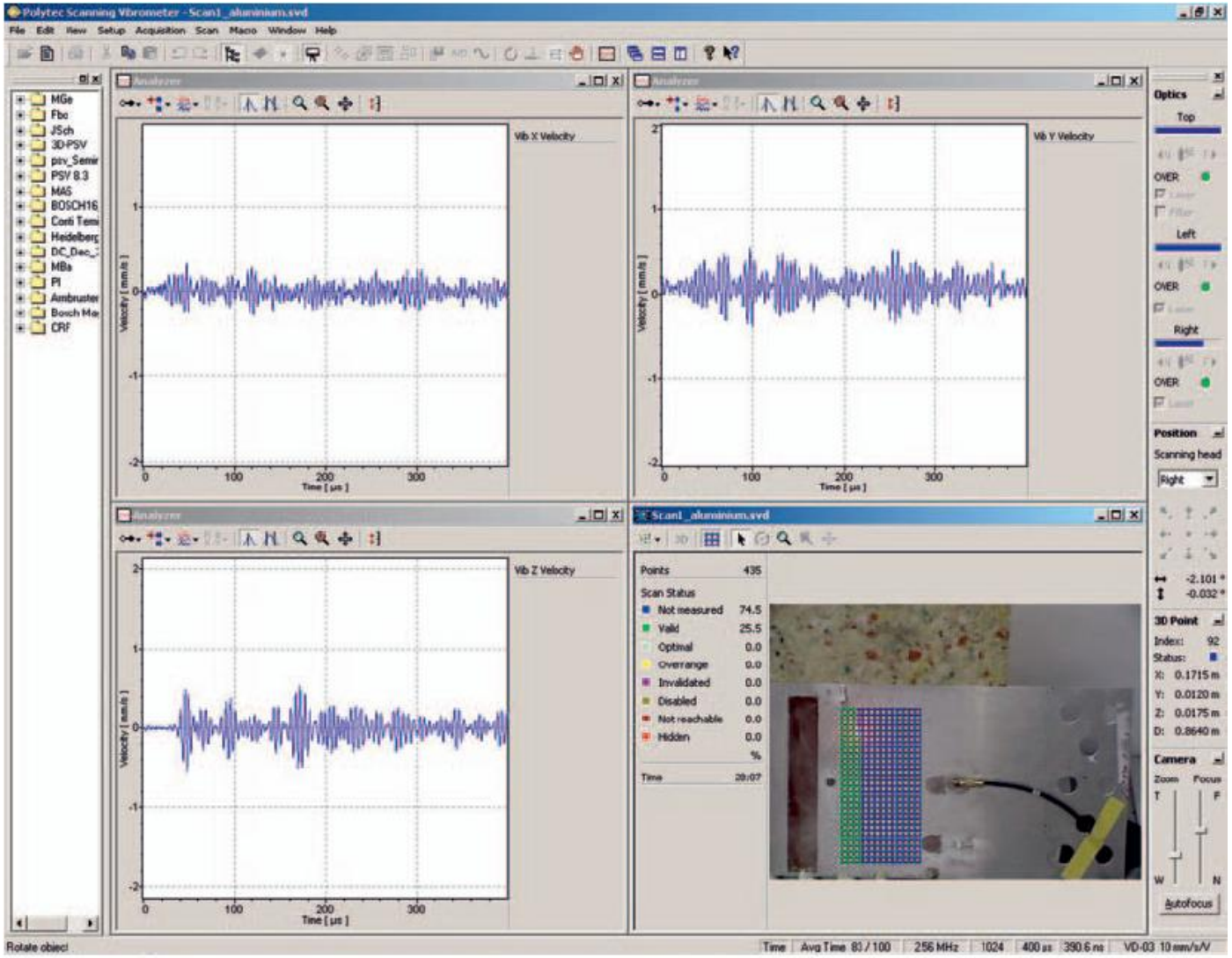
Non-Destructive Testing



Damage Detection using Lamb Waves

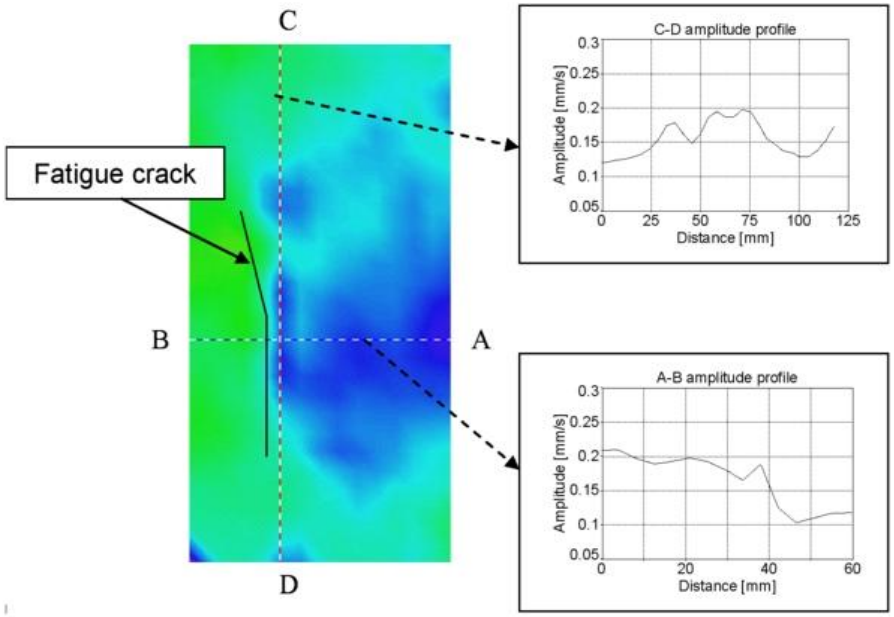
- Time reponse of ultrasonic pulse for hundreds of points
- Wave propagation visualized
- De/re-flection of propagating wave shows material defects

Damage Detection using Lamb Waves

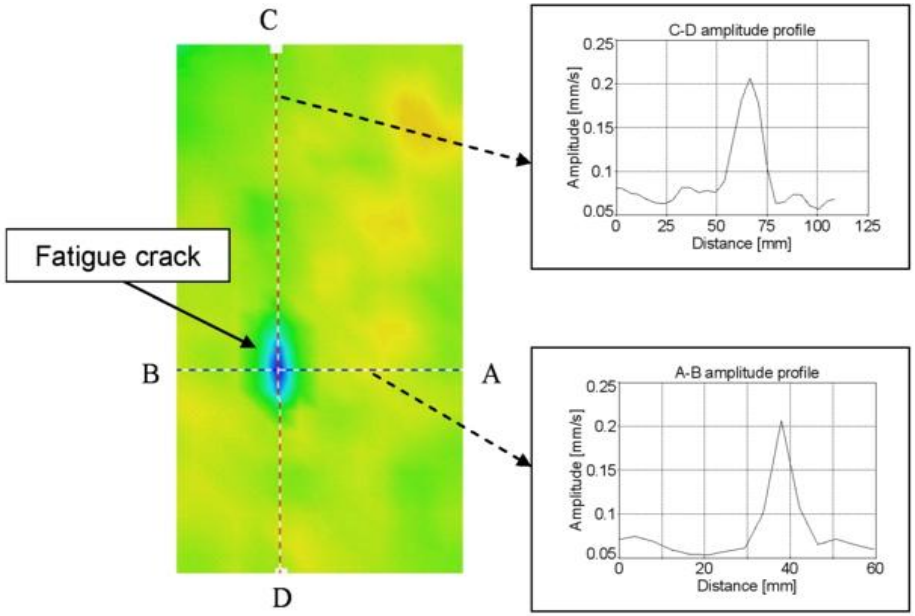


Damage Detection using Lamb Waves

3-D Measurements



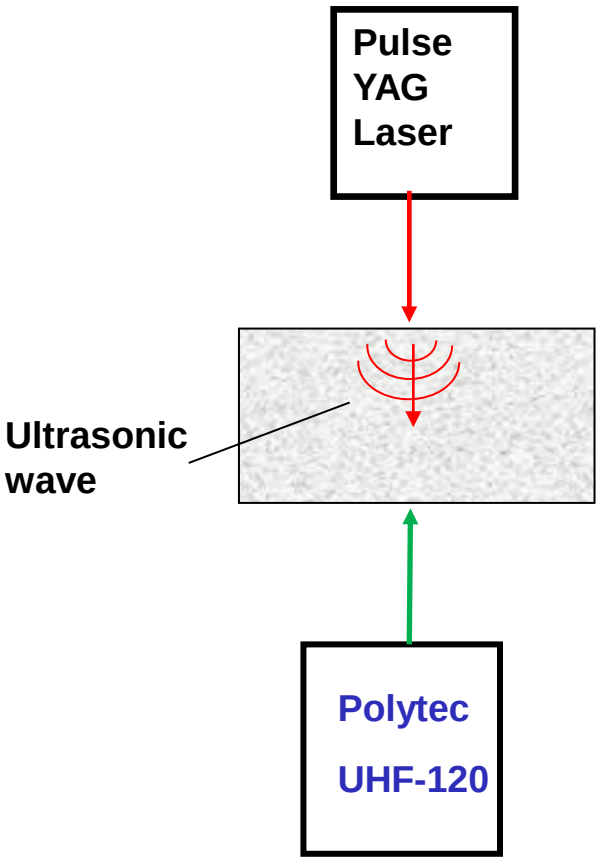
In-plane at 75kHz



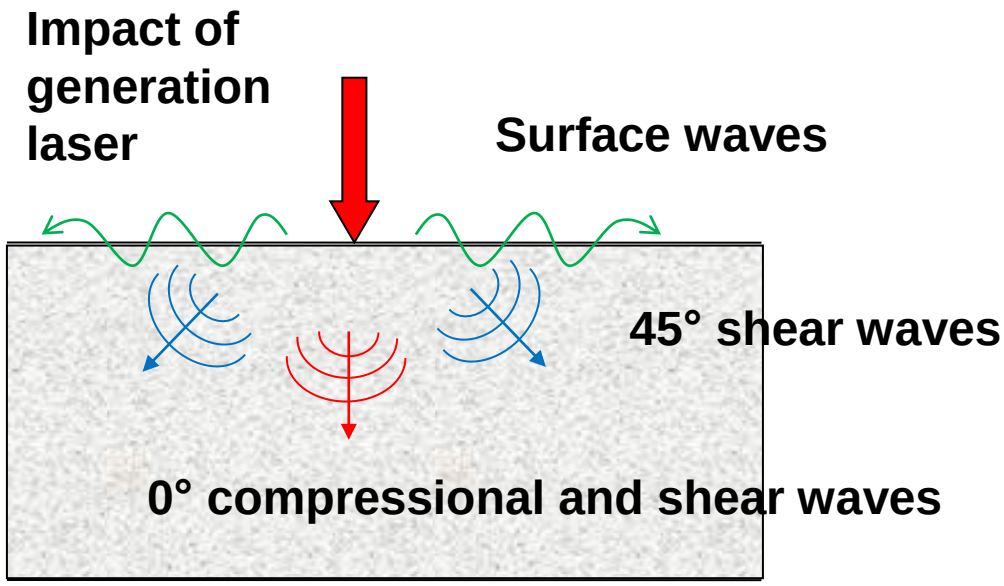
Out-of-plane at 325kHz

Fatigue crack in metallic structure. RMS amplitude contour map

Excitation by Pulsed Nd:Yag Laser



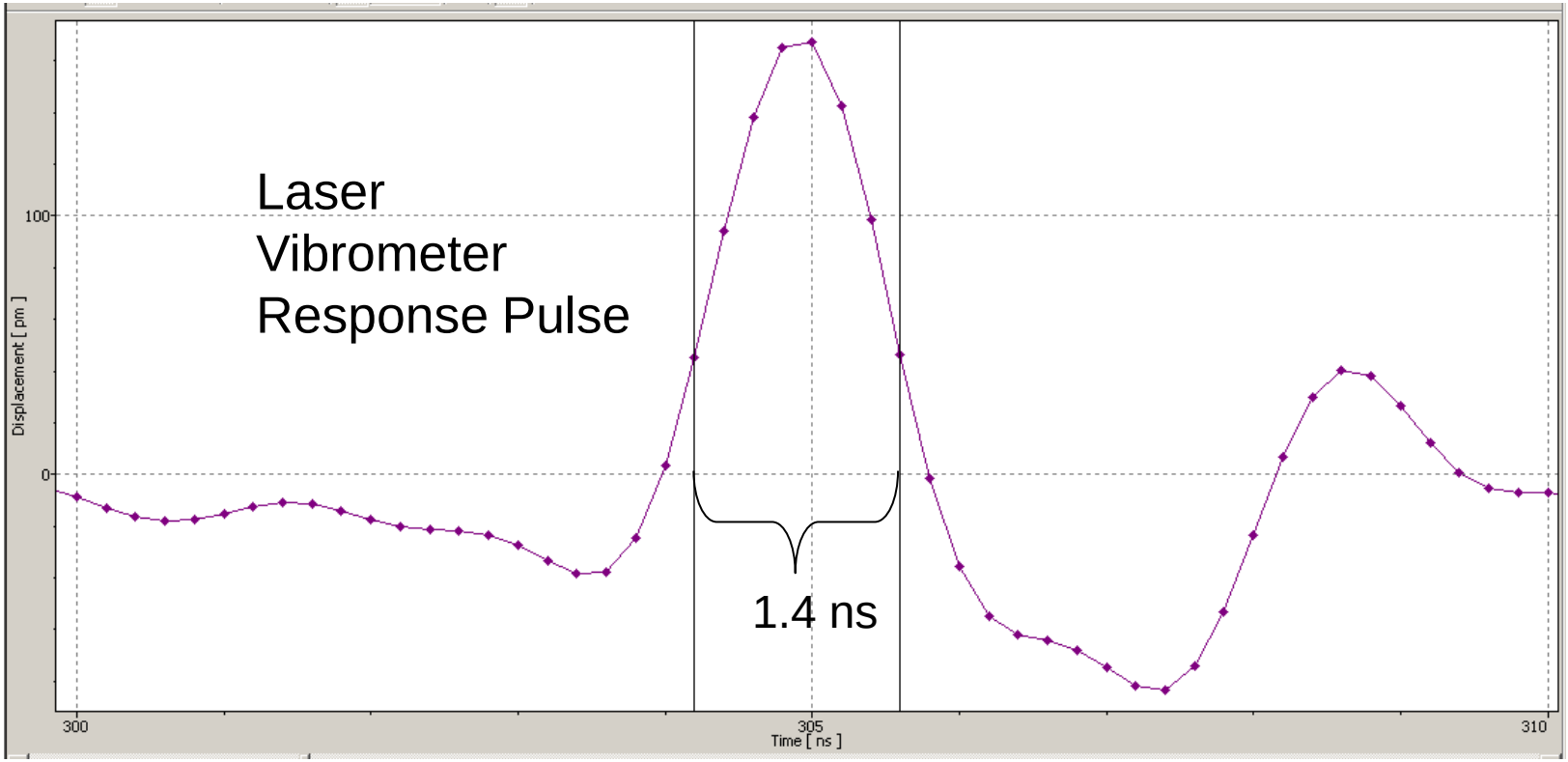
Ultra short laser pulse (1ns) creates a series of ultrasonic waves in bulk and surface of substrate



Excitation by Pulsed Nd:Yag Laser

Generation Laser: Nd:YAG Laser with 1ns Pulse Width

Polytec Ultra High Frequency Vibrometer (UHF-120) with 1.2 GHz Bandwidth

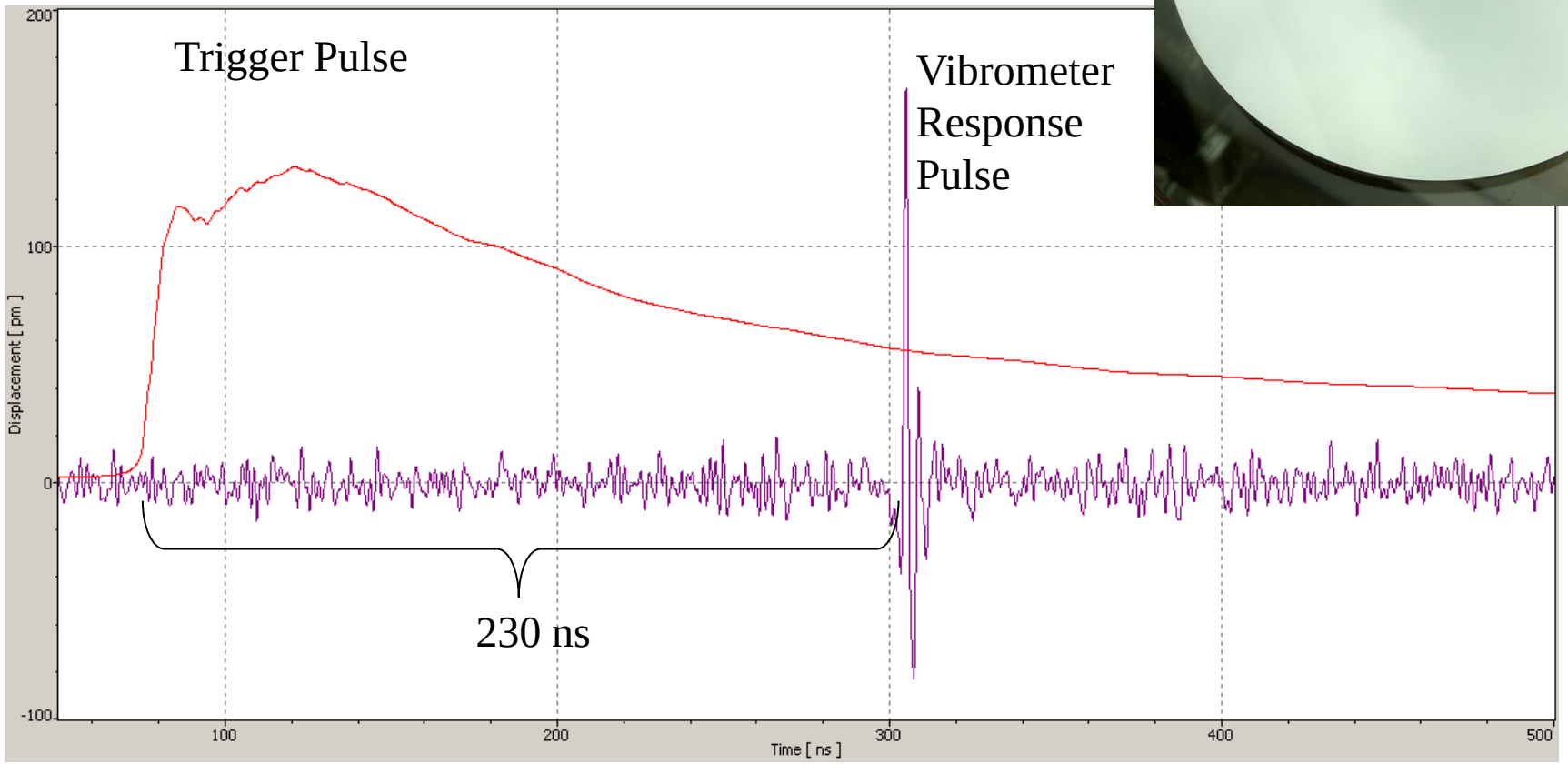


Polished Disk Surface

Thickness Measurement Disk

Time of Flight = 230 ns & Thickness = 1.2mm

→ Speed of Sound in Disk = 5,220m/s



Conclusion

Laser Vibrometry:

- is well suited for broad range of ultrasonic applications

- real-time, broadband measurement with frequency bandwith to GHz

- highly Sensitive measurement with resolution down to *picometer* level

-supported by Application Engineers knowledgeable with ultrasonic applications

-available for measurements services and rentals.

Advancing Measurements by Light • www.polytec.com