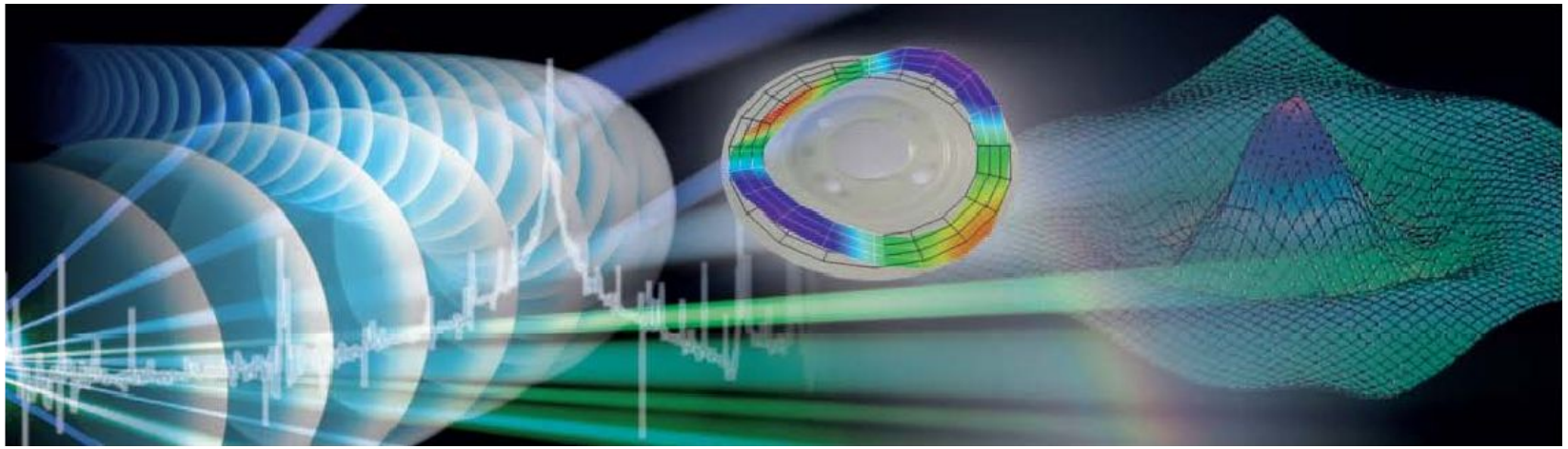
Measuring Ultra-high Frequency Vibrations of Micro Structures



The Polytec UHF-120 Laser-Doppler-Vibrometer

MicroNanoTec 2010

Dr. Heinrich Steger, Polytec GmbH

Company Portrait

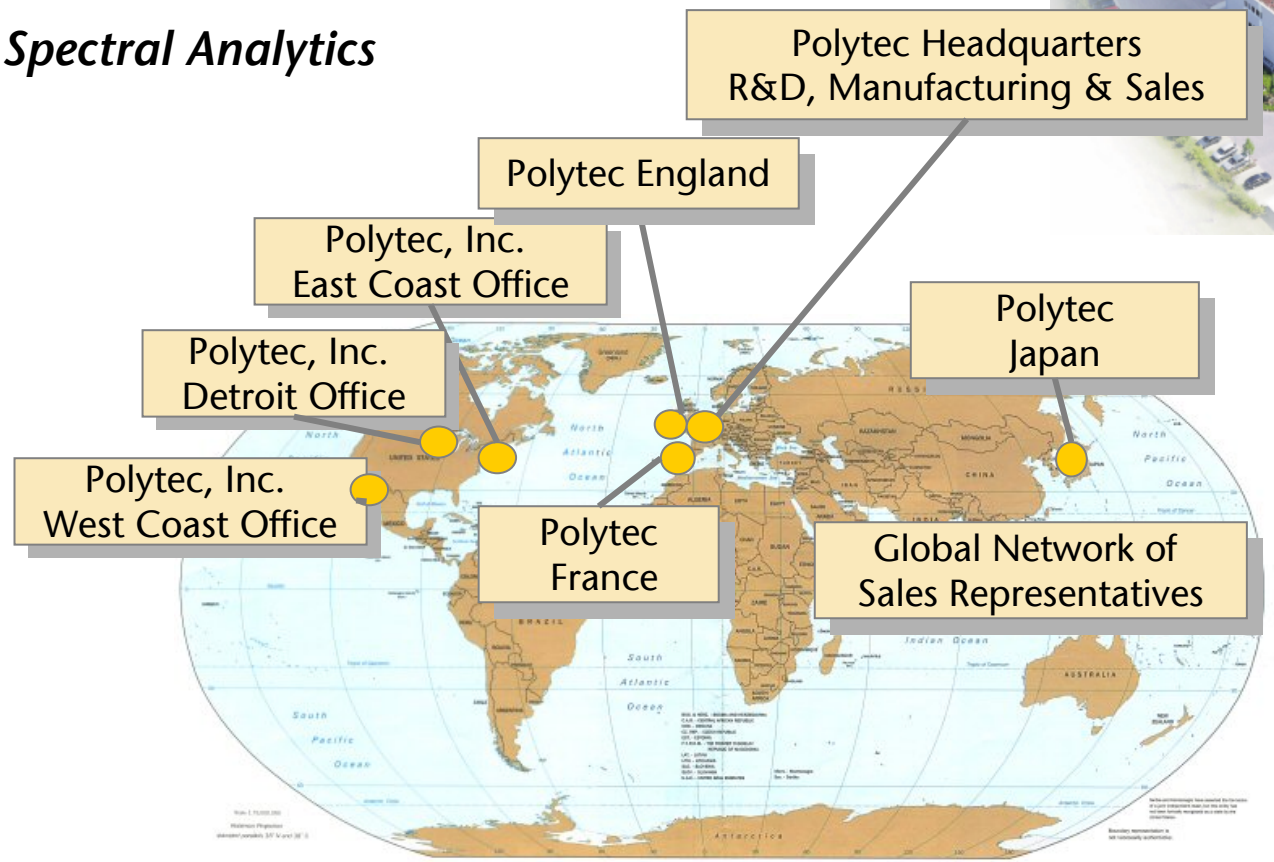
Business Units

Optical Measurement Systems

Photonics

Spectral Analytics

1967 Foundation



Polytec today

300 EMP worldwide

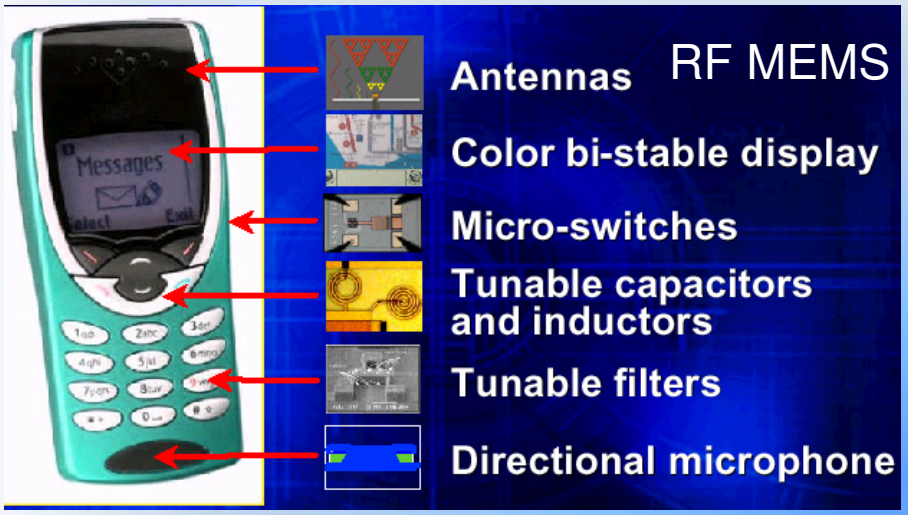
50 EMP R&D

Content

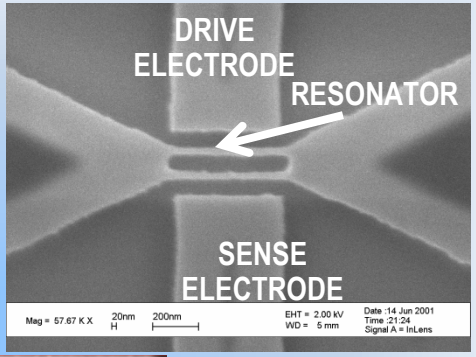
- Motivation
- The Scanning Ultrahigh Frequency Vibrometer UHF-120-SV
  - Technology + Innovation
  - Components
  - Spezifications
  - Measurement examples

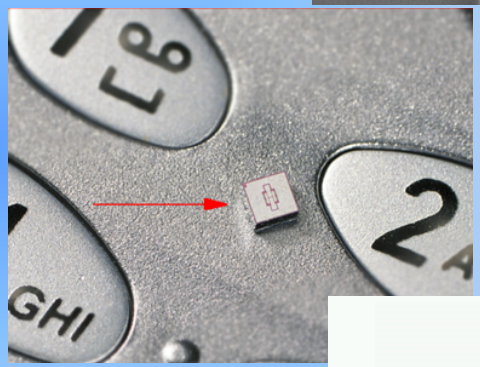
Motivation: UHF-Applications

- **Ultra-high-frequency mechanical vibrations are ubiquitous**

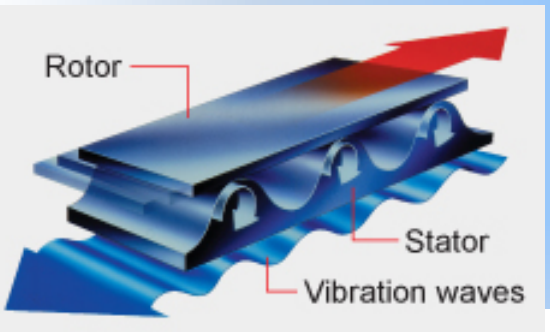


NEMS



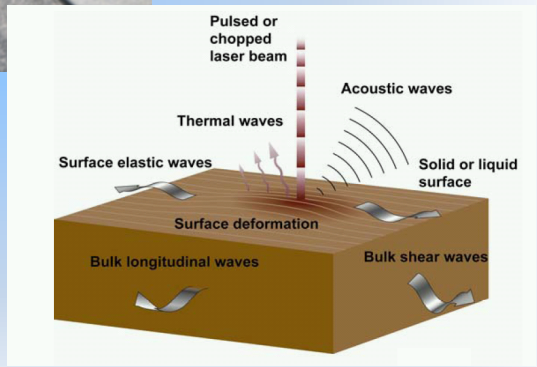


BAW or SAW filters



Ultrasonic motors

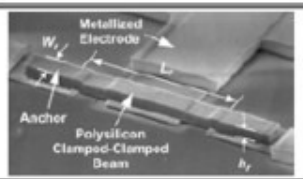
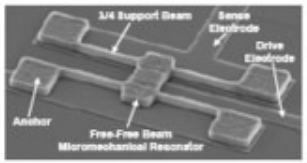
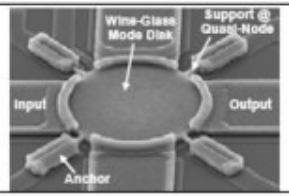
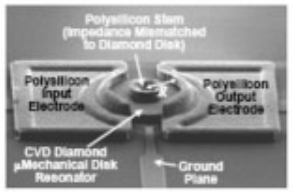
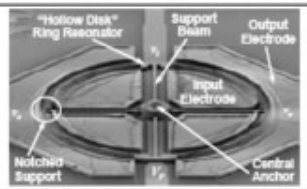
Ultrasound Imaging



Laser Ultrasonics

RF-MEMS

Dr. Clark Nguyen at UC Berkeley

Device	Photo	Performance	Applications	Research Issues
CC-Beam Resonator [17]		Demo'ed: Q ~8,000 @ 10MHz (vac) Q ~50 @ 10MHz (air) Q ~300 @ 70MHz (anchor diss.) Q drop w/ freq. limits freq. range Series Resistance, R_x ~5-5,000Ω	Reference Oscillator HF-VHF Filter HF-VHF Mixer-Filter (arrays of the above)	power handling thermal/aging stability impedance vacuum packaging
FF-Beam Resonator [6]		Demo'ed: Q ~20,000 from 10-200 MHz Q ~2,000 @ 90 MHz (air) No drop in Q with freq. Freq. Range: >1GHz; unlimited w/ scaling and use of higher modes Series Resistance, R_x ~5-5,000Ω	Reference Oscillator HF-UHF Filter HF-UHF Mixer-Filter Ka-Band? (arrays of above)	freq. extension power handling thermal/aging stability impedance vacuum packaging
Wine-Glass Disk Res. [21]		Demo'ed: Q ~156,000 @ 60 MHz (vac) Q ~8,000 @ 98 MHz (air) Perimeter support design nulls anchor loss to allow extremely high Q Freq. Range: >1GHz; unlimited w/ scaling Series Resistance, R_x ~5-5,000Ω	Reference Oscllator HF-UHF Filter HF-UHF Mixer-Filter (arrays of the above)	freq. extension power handling thermal/aging stability impedance
Contour-Mode Disk Res. [11]		Demo'ed: Q ~11,555 @ 1.5 GHz (vac) Q ~10,100 @ 1.5 GHz (air) Balanced design and material mismatching anchor-disk design nulls anchor loss Freq. Range: >1GHz; unlimited w/ scaling and use of higher modes Series Resistance, R_x ~50-50,000Ω	RF Local Oscillator VHF-S-Band Filter VHF-S-Band Mixler Ka-Band? RF Channel-Select (arrays of above)	thermal/aging stability impedance Xmit power handling
Hollow Disk Ring Res. [12]		Demo'ed: Q ~14,600 @ 1.2 GHz (vac) λ/4 support design nulls anchor loss Freq. Range: >1GHz; unlimited w/ scaling and use of higher modes Series Resistance, R_x ~50-5,000Ω	RF Local Oscillator UHF-S-Band Filter UHF-S-Band Mixler Ka-Band? RF Channel-Select (arrays of above)	thermal/aging stability impedance Xmit power handling

Vibration Measurement in R&D

- Undisturbed reaction-free measurement of subtle high-frequency mechanical vibrations

☞ **Non-contact optical Measurement**

- High-frequent solid vibrations have very short acoustical wavelengths ~ µm

☞ **Demand for high lateral resolution**

- Ultra-high frequent vibrations typically habe very small amplitudes ~ pm

☞ **Demand for high amplitude resolution**

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Vibration Measurement in R&D

- High Frequencies => high velocities
- ☞ **Large velocity measurement range**
- Transient Processes
- ☞ **Real-time measurement in t-domain**
- Fast spectral characterization of samples
- ☞ **Rapid broadband measurement with instantaneous representation in f-domain**
- Thermosensitive micro electronic components
- ☞ **Minimum energy deposition**

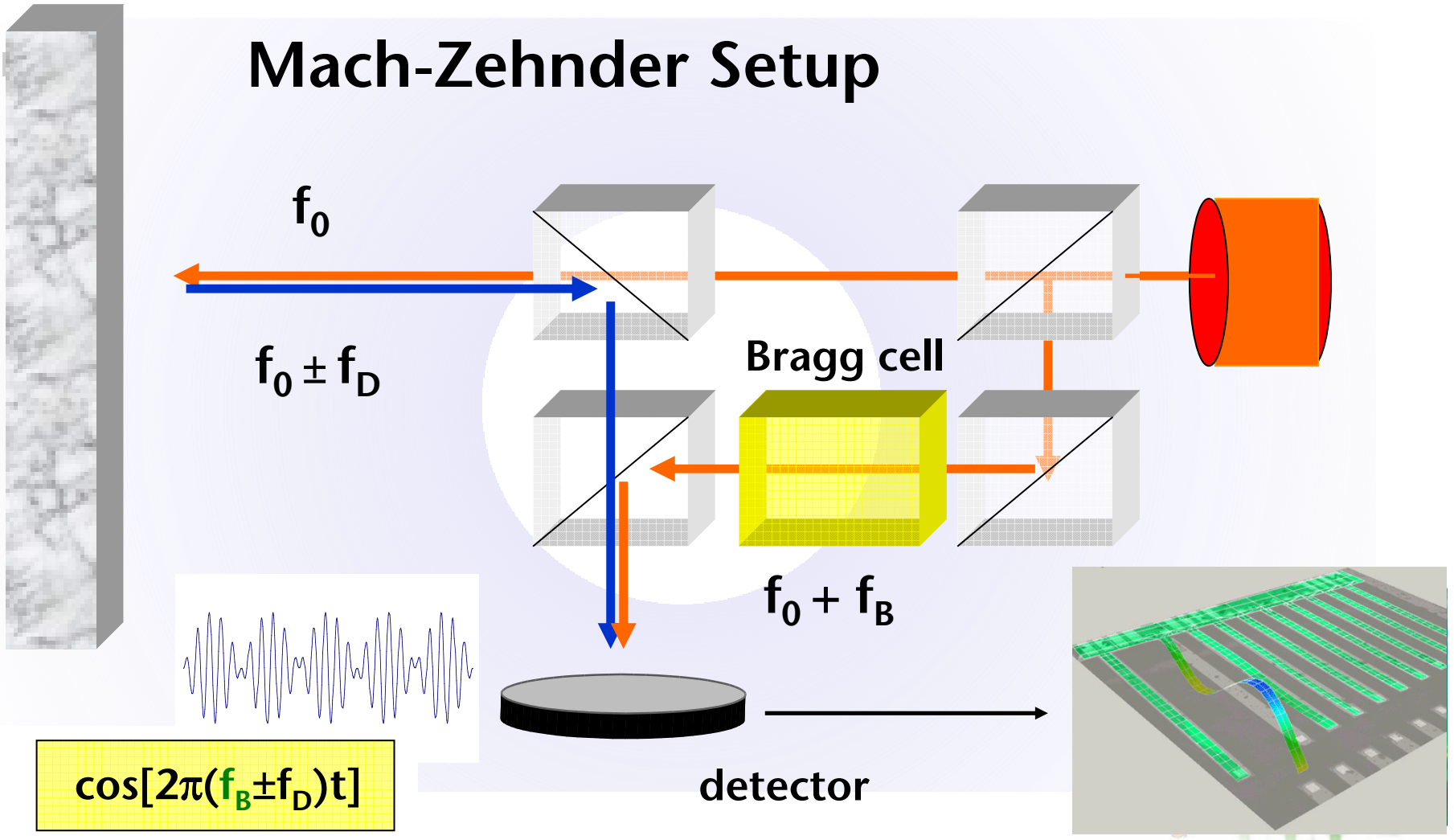
Laser-Doppler-Vibrometer

Well established in MEMS & Material Research

- Non-contact vibration measurement
- High sensitivity and accuracy
- High resolution in the pm-range
- High lateral resolution due to small focus
- Min. energy transfer due to small laser power
- Fast broadband measurement with instantaneous frequency spectrum
- Measurement of transients in t-domain

Laser Doppler Vibrometer

Mach-Zehnder Setup



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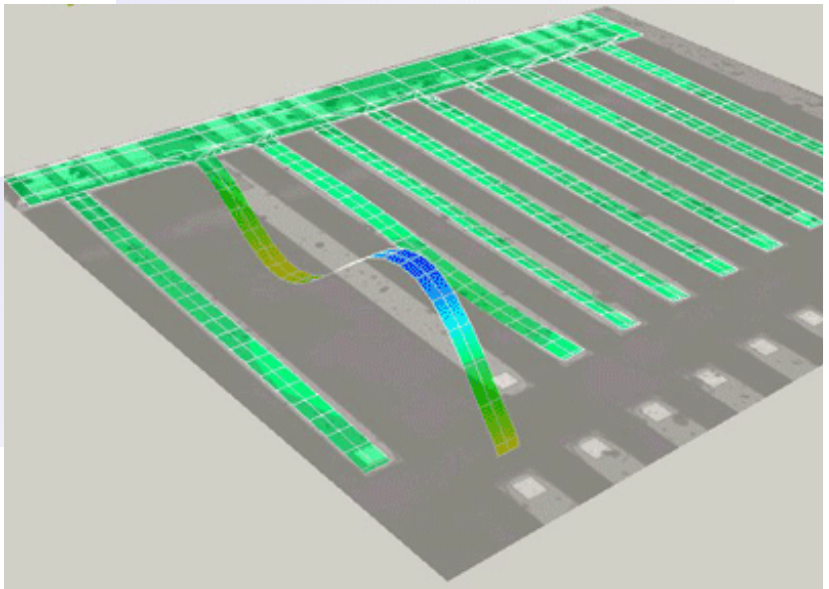
Current Vibrometer Specifications

- Frequency bandwidth ≤ 24 MHz
- Velocity ≤ 20 m/s
- Amplitude resolution: pm
- Maximum displacement ranges for HF-decoder (> 2.5 MHz) is limitet at 70 nm



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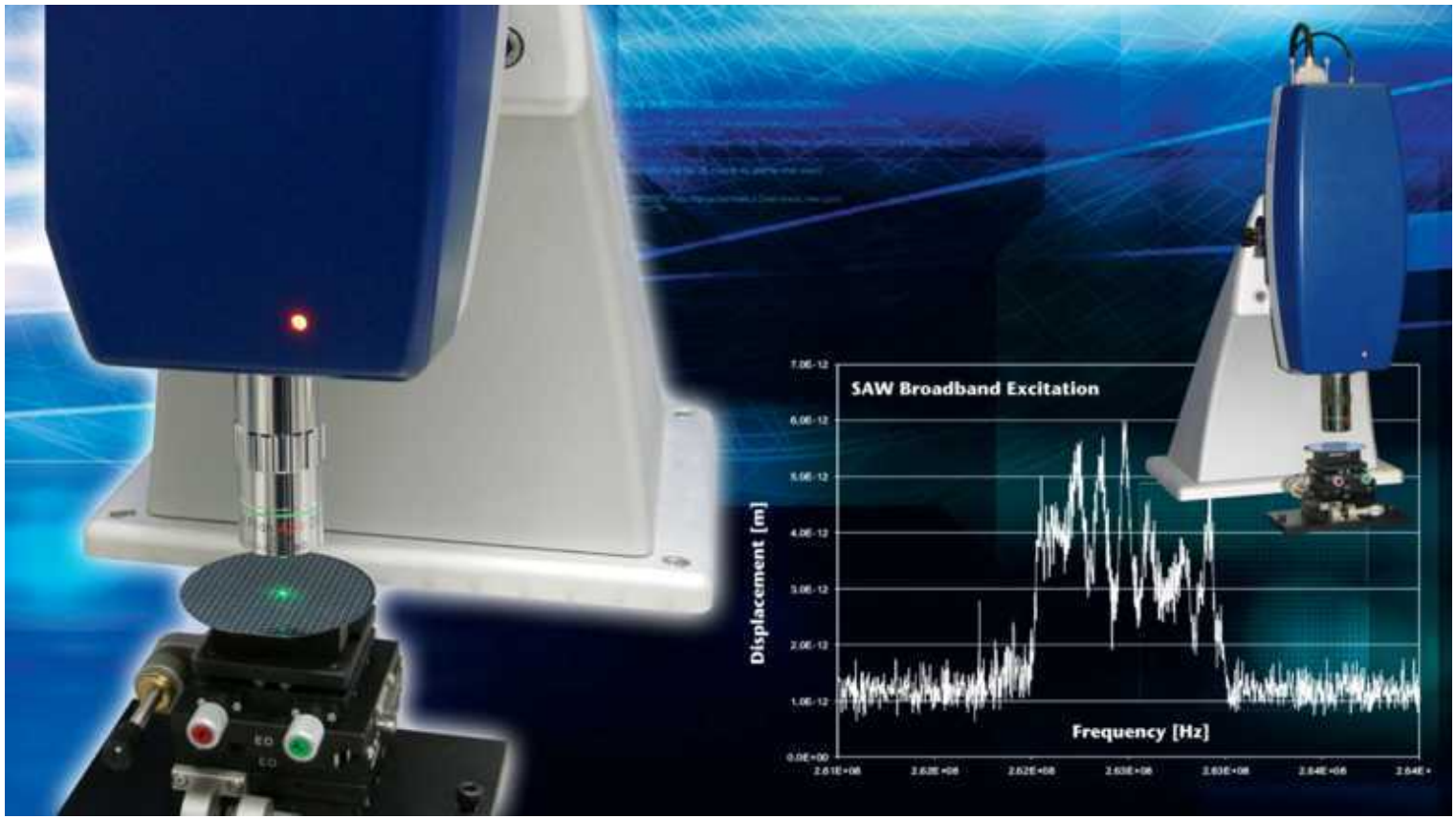
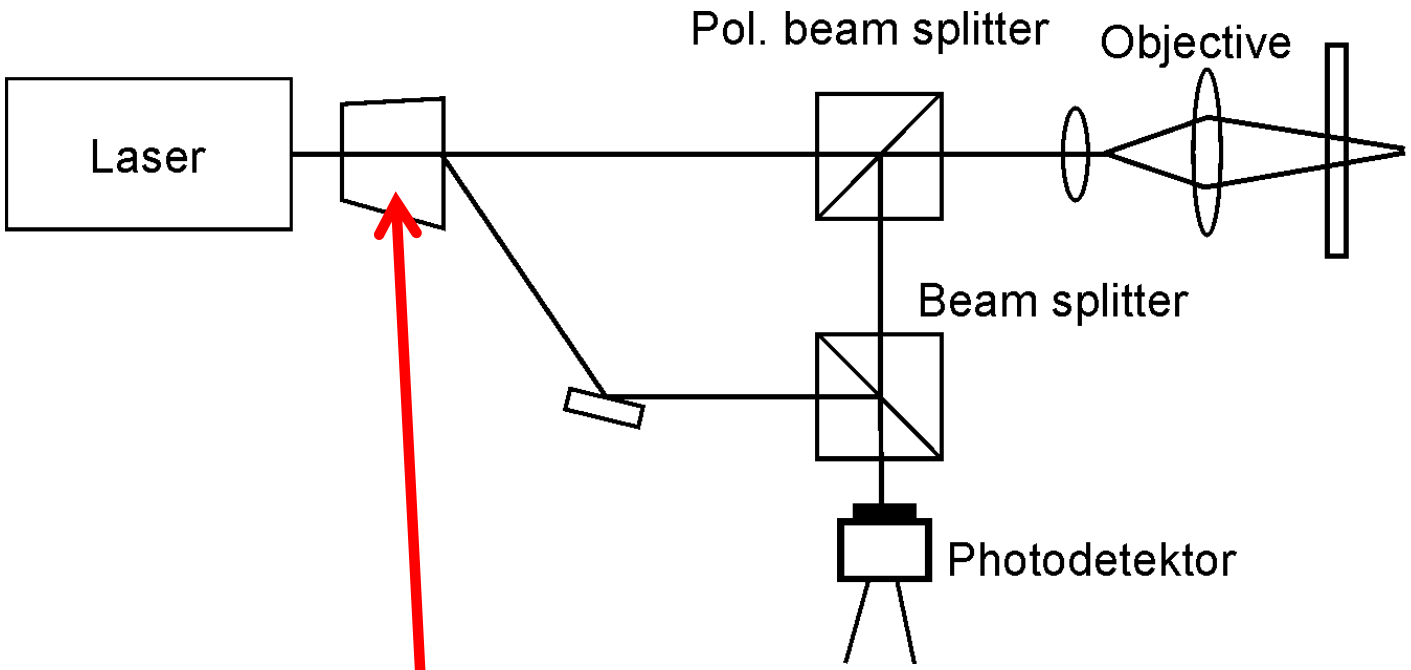
Typical HF-Applications

- **Crystal Oszillators**
  < 50 MHz
- **Ultrasonic Motors**
  0.1 MHz – 150 MHz
- **MEMS program. Clock Oszillators**
  1 MHz – 200 MHz
- **Ultrasound Imaging**
  10 MHz – 250 MHz
- **Laser Ultrasound and Thin Films**
  10 MHz – 500 MHz
- **NEMS**
  50 MHz – 1 GHz
- **RF – MEMS**
  20 MHz – 3 GHz
- **BAW/SAW Filters**
  10 MHz - >> 3 GHz

The UHF-120-SV Ultra-high Frequency Scanning Vibrometer

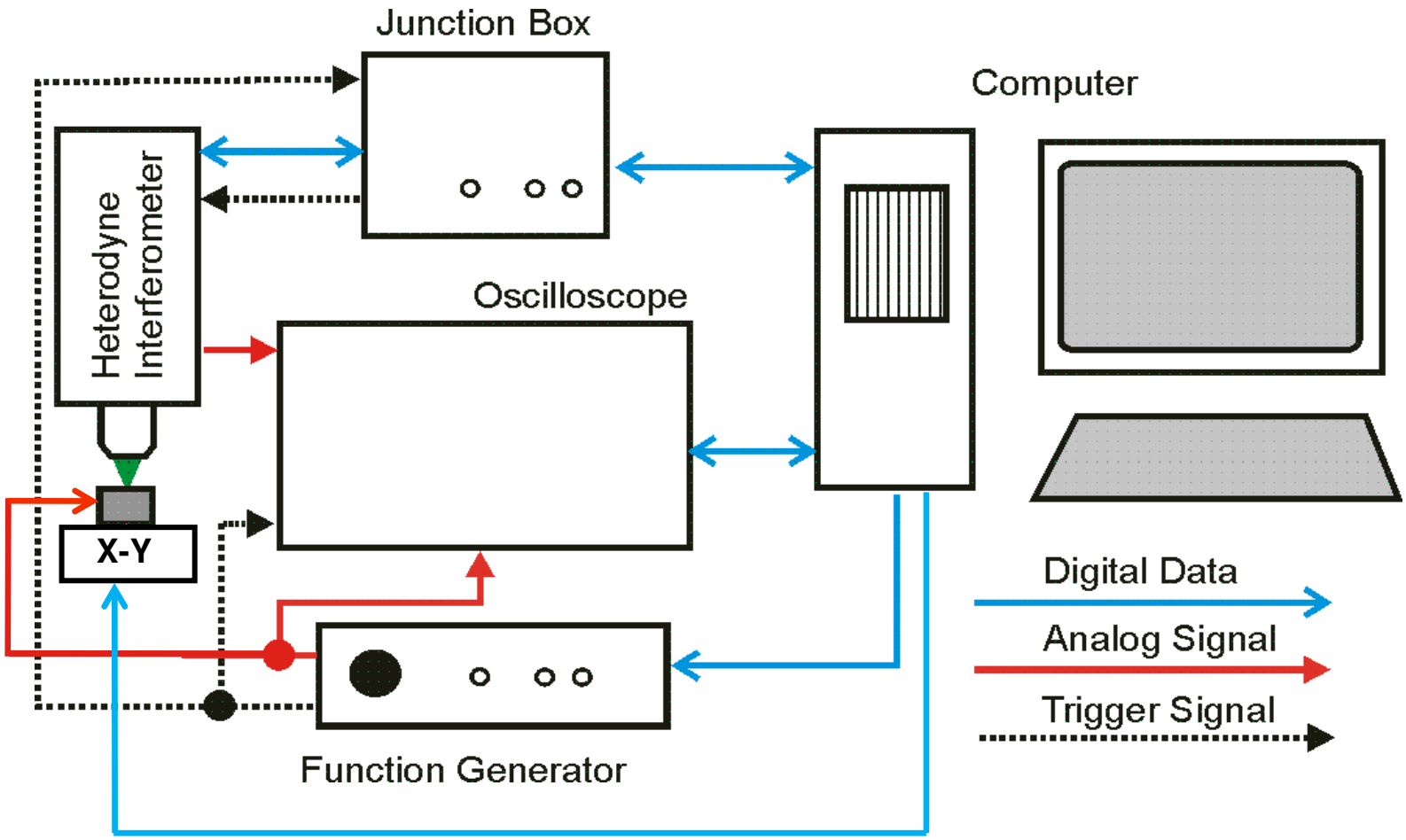


Optical Setup

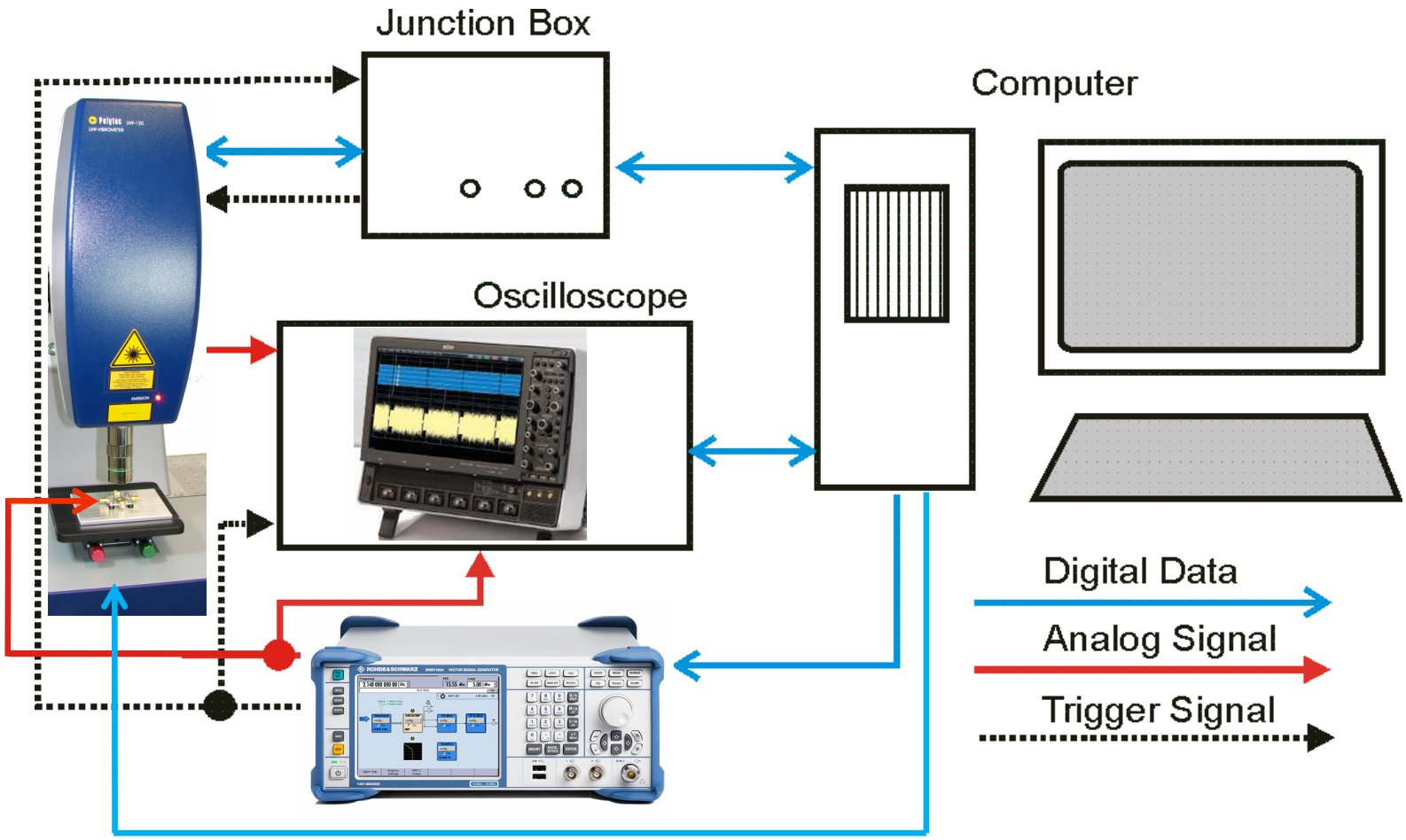


- Innovations:
  - Carrier frequency $f_{carrier} > 600$ MHz
  - Signal processing for Measurements up to 1,2 GHz

Components

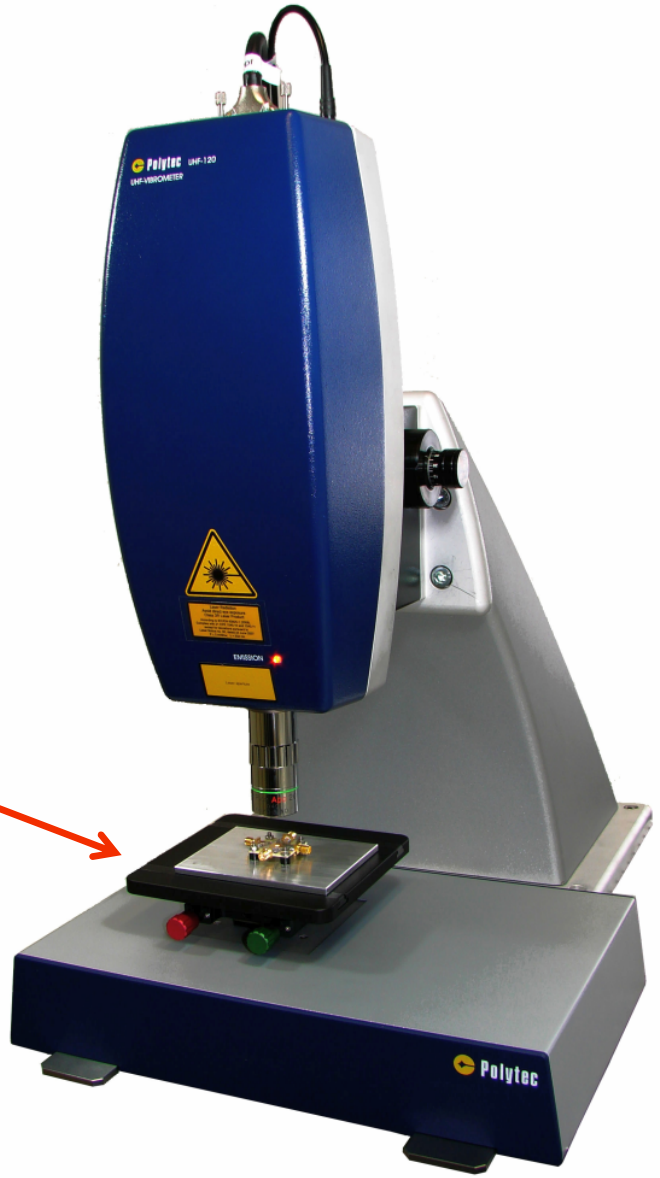

Junction Box
Computer
Heterodyne Interferometer
Oscilloscope
X-Y
Digital Data
Analog Signal
Trigger Signal
Function Generator

Components


Junction Box
Computer
Oscilloscope
Digital Data
Analog Signal
Trigger Signal

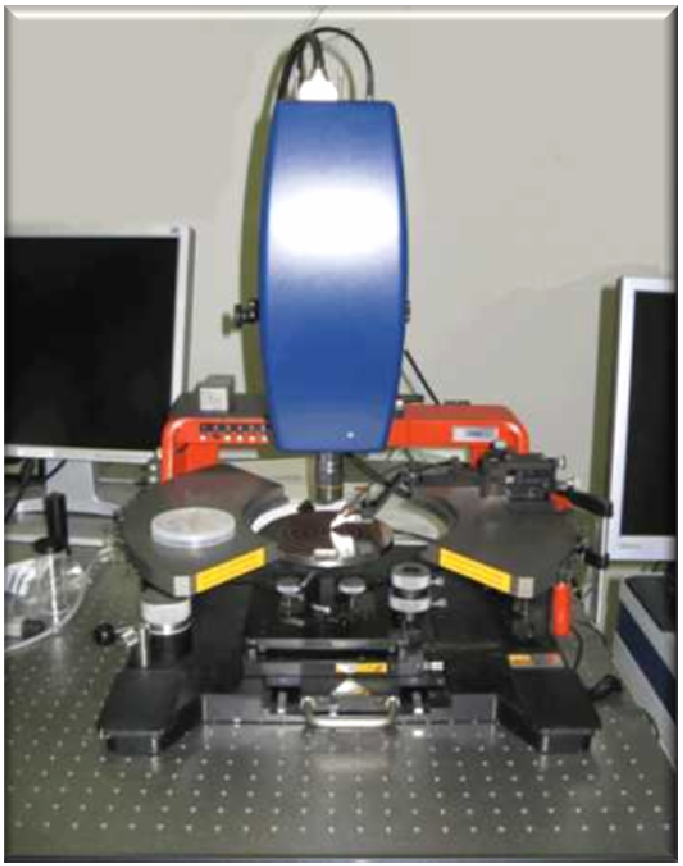
Heterodyne Interferometer and Scanning Hardware

- X-Y Traverse
- Scanning
- Operational deflection shape measurement
- „Slow-Motion“-Visualisation



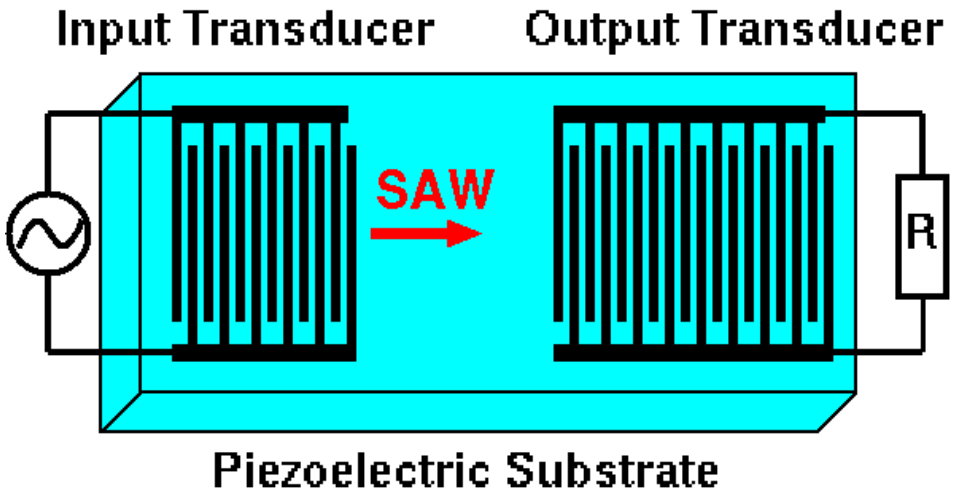
Integration in probe stations

- For measurements on wafer level
- Simple Integration into a probe station
- Positioning of laser spot with integrated camera
- Automated routine measurements possible



Surface Acoustic Wave Filter

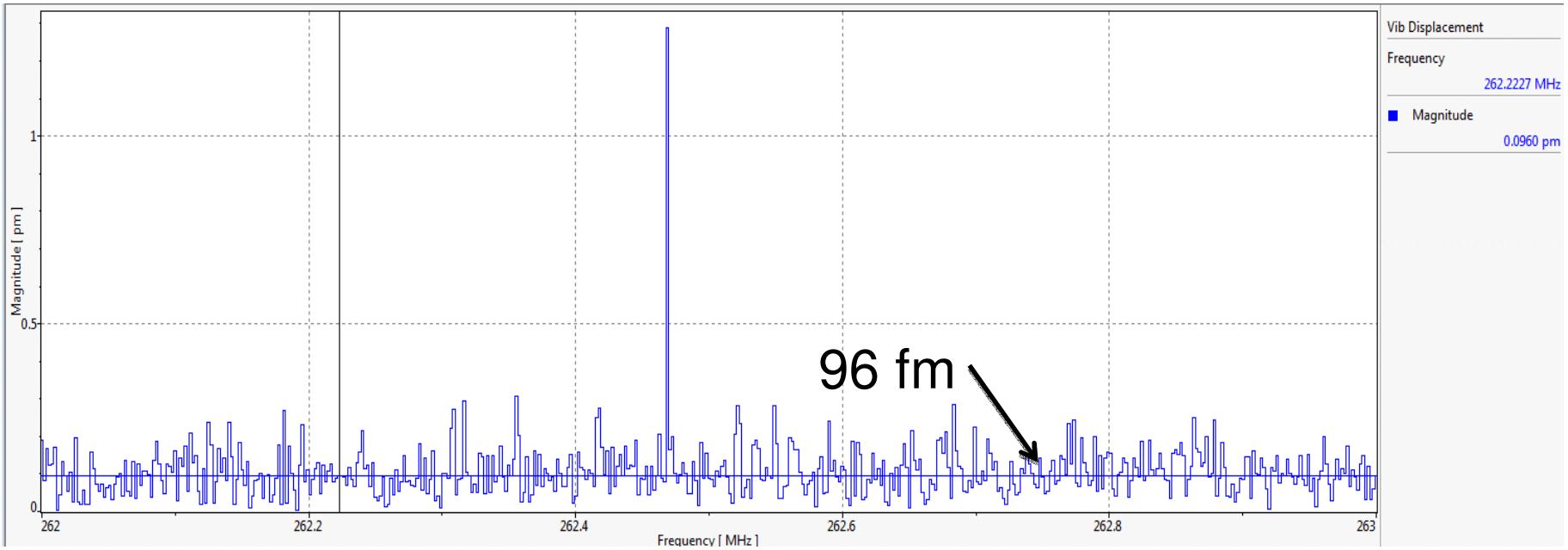
- **Electrical Input**
  => Conversion in acoustical surface wave
  => Filtering with specific characteristic
  => Conversion in **electrical Output signal**



Example: SAW-Filter

Sensitivity: Signal/Noise Ratio

SAW filter with narrow band excitation



Note: Using the excitation signal as a reference and complex averaging will reduce the noise level

Example: SAW-Filter

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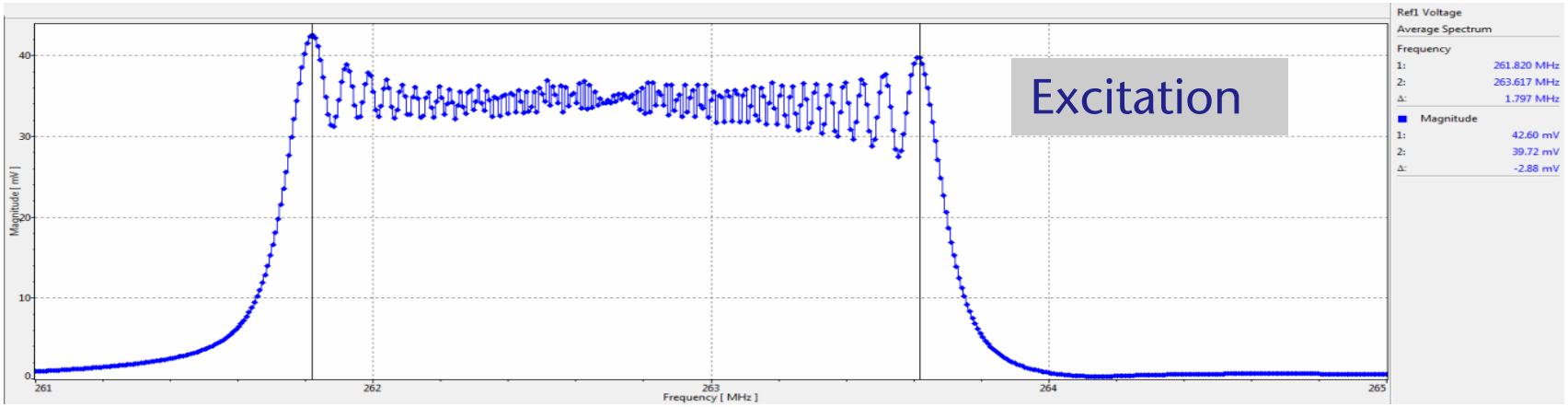
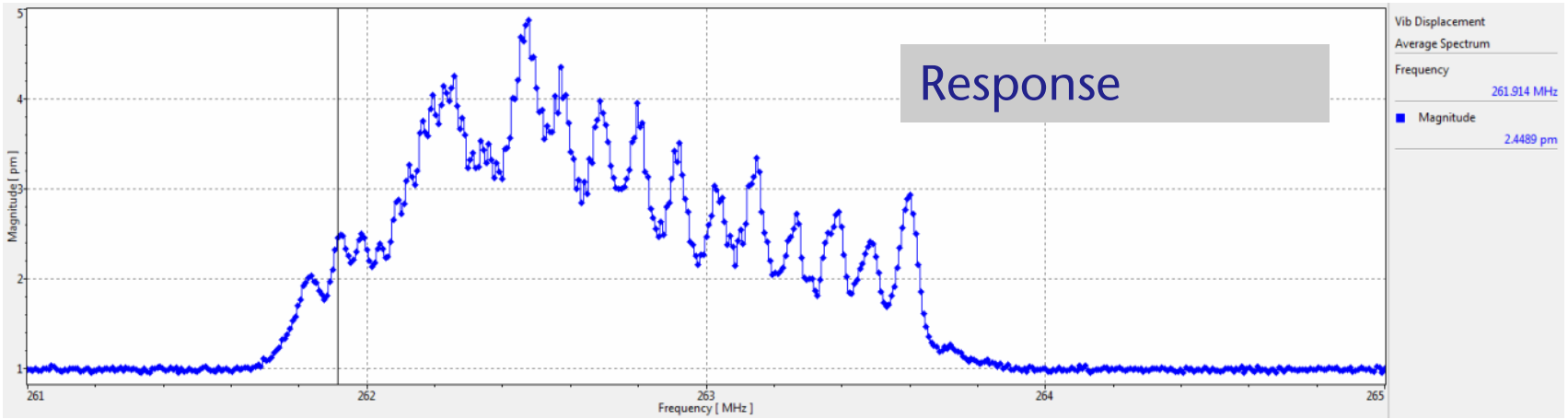
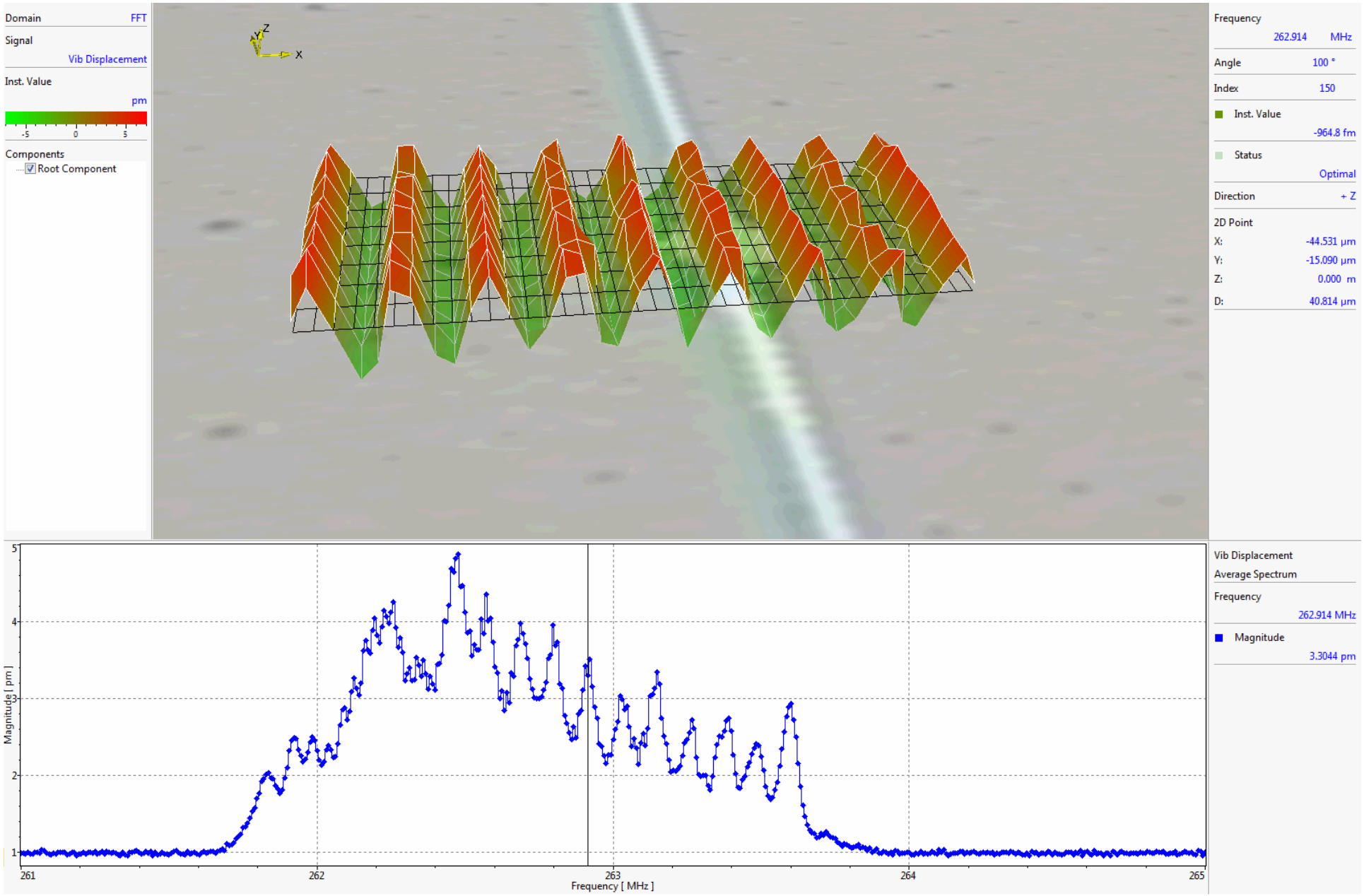
Measurement with Broadband Excitation



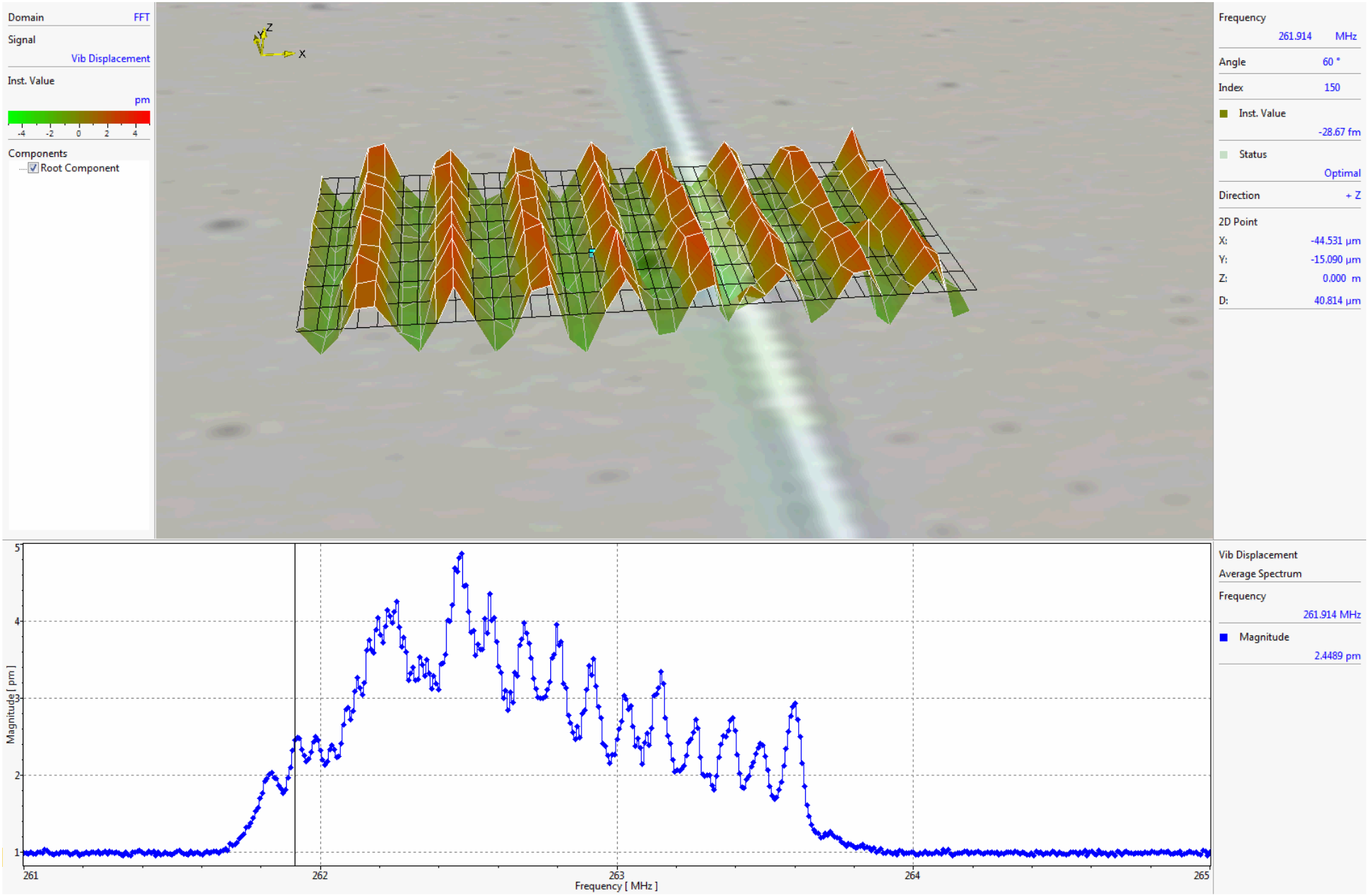


Broadband measurements with high amplitude accuracy

Example: SAW Filter 263 MHz

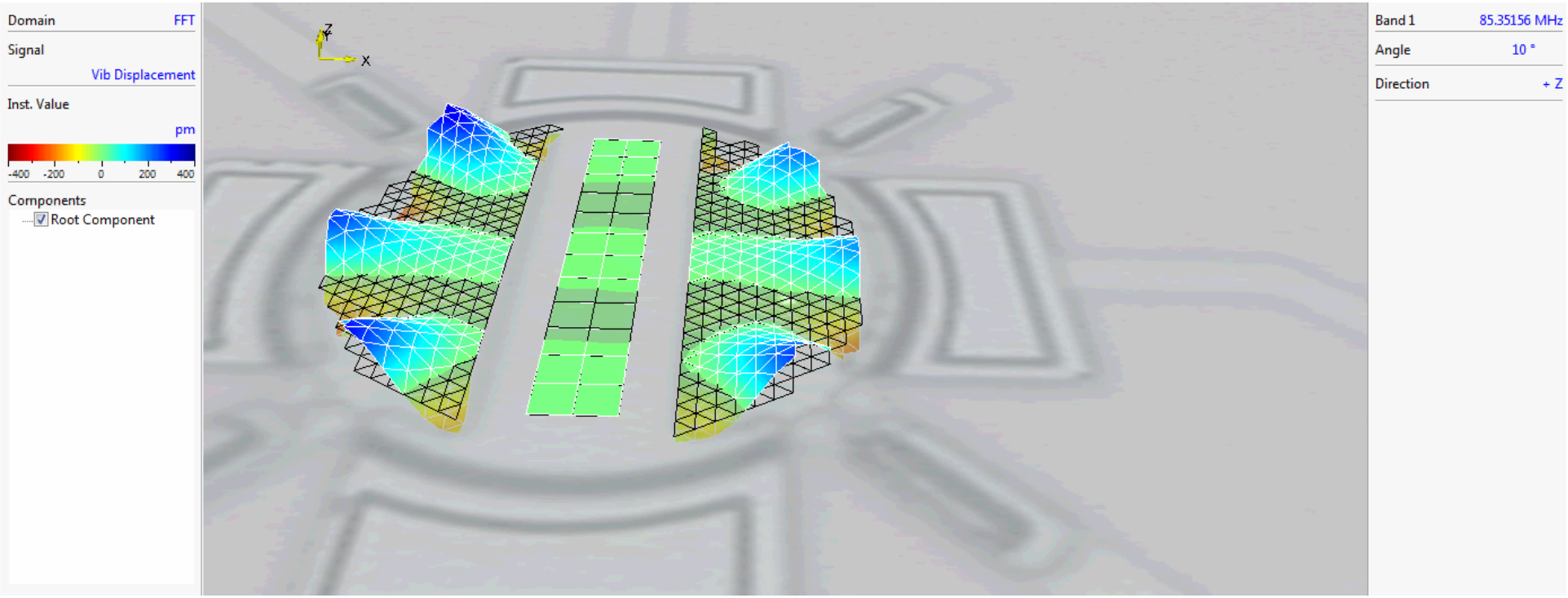


Example: SAW Filter 262 MHz



Resonator (UC Berkeley)

UHF-120 scanning measurement of resonance mode at 85 MHz



Summary

- The UHF-120 significantly expands the application range of Laser-Doppler-Vibrometry (RF-MEMS, SAW, Ultrasonic transducers, NEMS) :
  - f_{max} ~ 1,2 GHz,
  - v_{max} > 100 m/s
  - Amplitude resolution <2 pm (<500 fm with complex averaging)
- There is no comparable measurement instrument