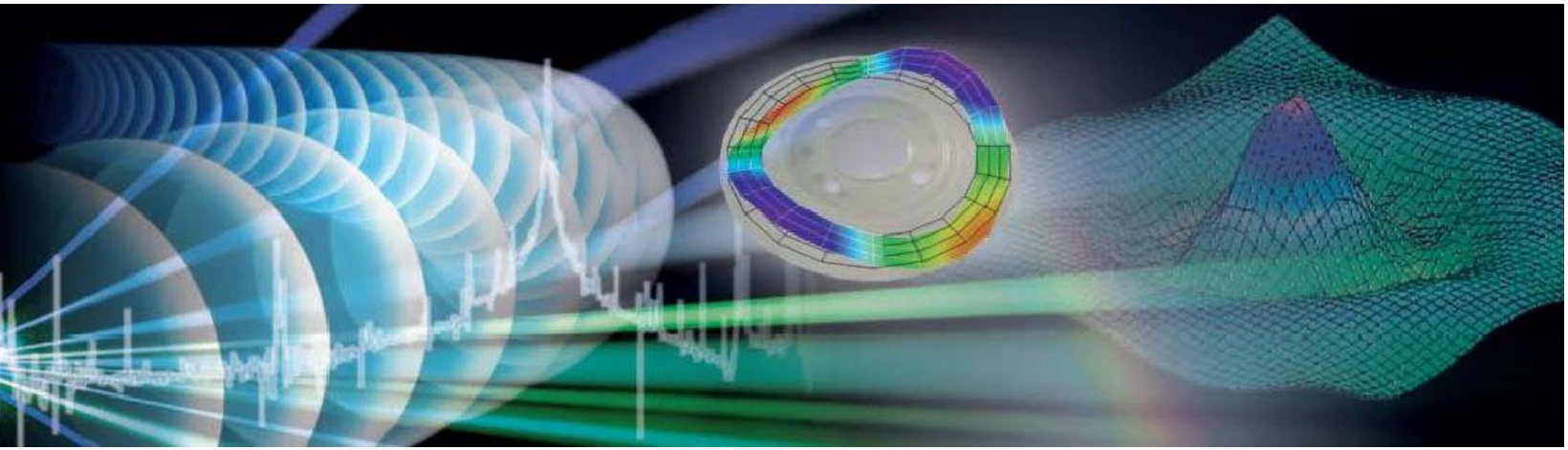
Optical Characterization of Microstructures



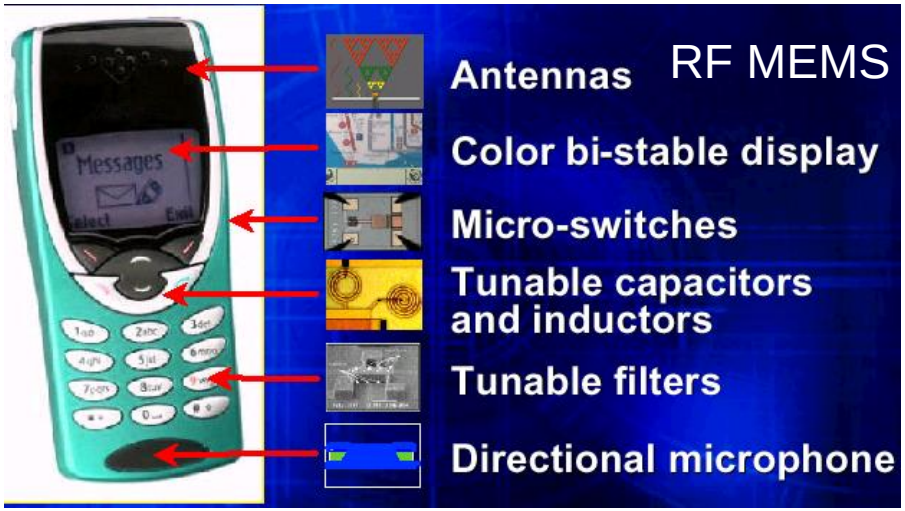
Measurement of Ultra-High-Frequency Mechanical Motion up to the GHz Regime

Heinrich Steger, Polytec GmbH

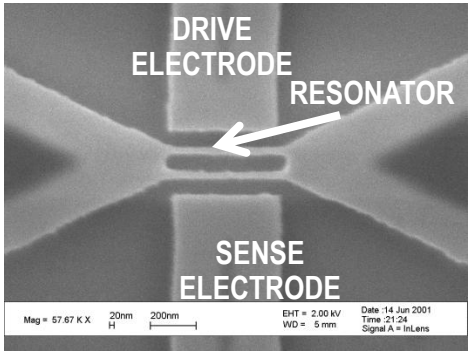
Agenda

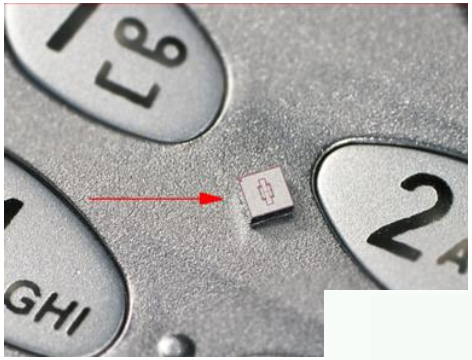
- **Why study UHF mechanical motions?**
  - Application fields
- **Measurement tasks**
  - RF-MEMS
  - SAW filters
  - Ultrasonic transducers
- **UHF Laser-Doppler-Vibrometry**
  - System design
  - Measurement capabilities

UHF Application Fields

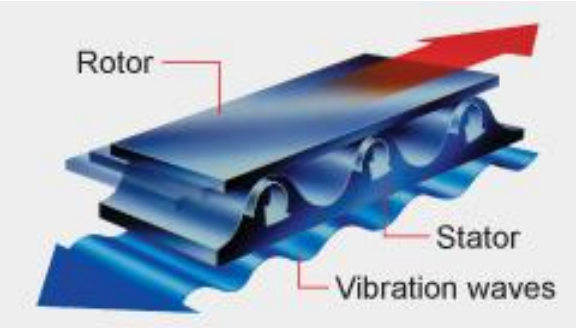


NEMS



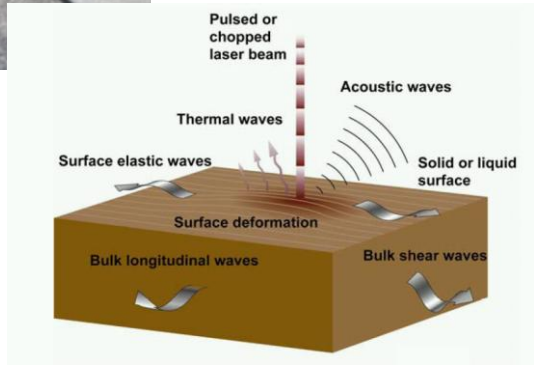


BAW or SAW filters



Ultrasonic motors

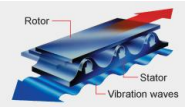
Ultrasound Imaging



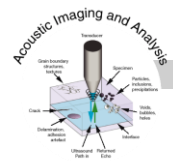
Laser Ultrasonics

Typical HF applications

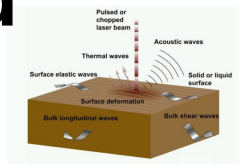
- **Crystal Oszillators**
  < 250 MHz



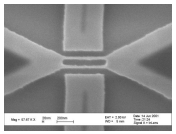
- **Ultrasonic Motors**
  0.1 MHz – 150 MHz
- **MEMS program. Clock Oszillators**
  1 MHz – 200 MHz



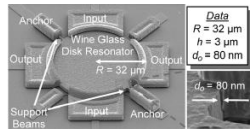
- **Ultrasound Imaging**
  10 MHz – 500 MHz
- **Laser Ultrasound and Thin Films**
  10 MHz – 500 MHz



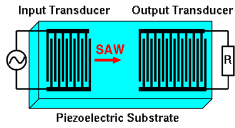
- **NEMS**
  50 MHz – 1 GHz



- **RF – MEMS**
  20 MHz – 3 GHz



- **BAW/SAW Filters**
  10 MHz - >> 3 GHz



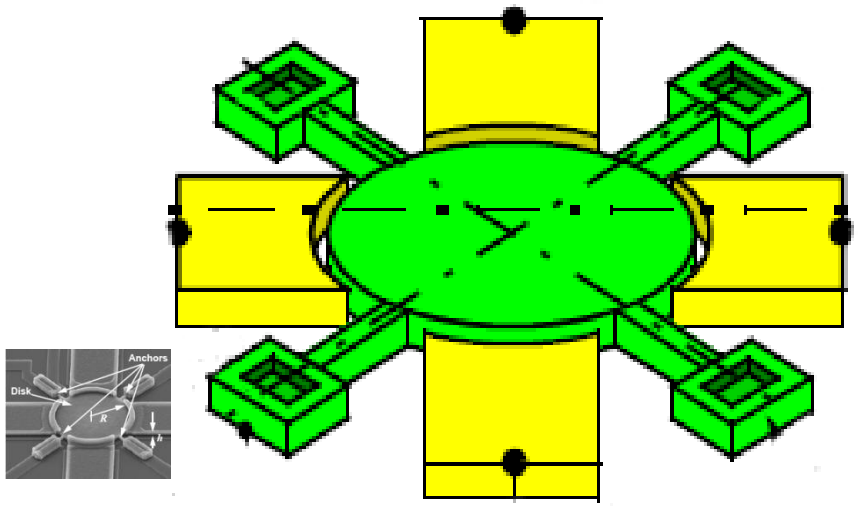
Challenges of HF Motion Measurement

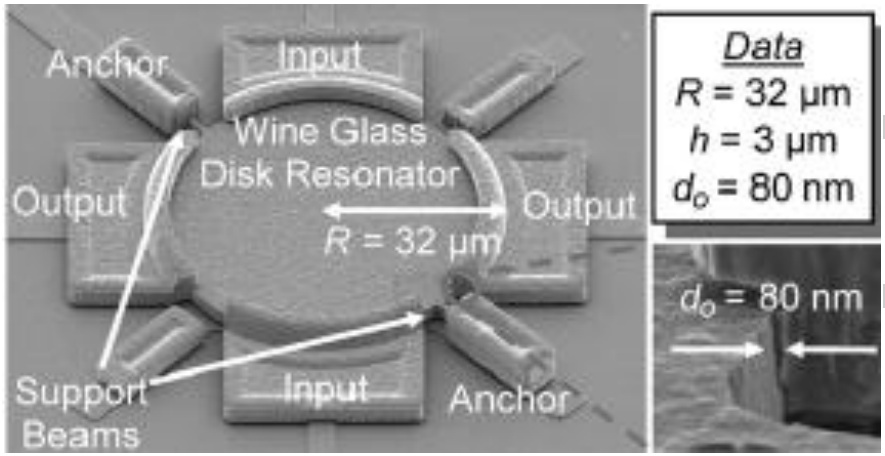
- **Ultra High Frequencies**
  - **High Frequency range ⇨ GHz Vibration sensor**
  - HF typically shows up at **small structures** and imply **shorter wavelengths** of acoustical waves, e.g. Wavelength < 10µm ⇨ **High lateral resolution**
  - Higher Frequencies means **smaller displacements** ⇨ **Resolve amplitudes < pm**
  - HF means **higher velocities ⇨ v > 100 m/s**

RF-MEMS

- RadioFrequency-MicroelEctroMechanicalSystem
  - Electronic components of which moving sub-millimeter-sized parts provide RF functionality
- Various types of RF MEMS components
  - CMOS integrable RF MEMS resonators and self-sustained oscillators with small form factor and low phase noise
  - RF MEMS tunable inductors
  - RF MEMS switches, switched capacitors and varactors

RF-MEMS Resonator

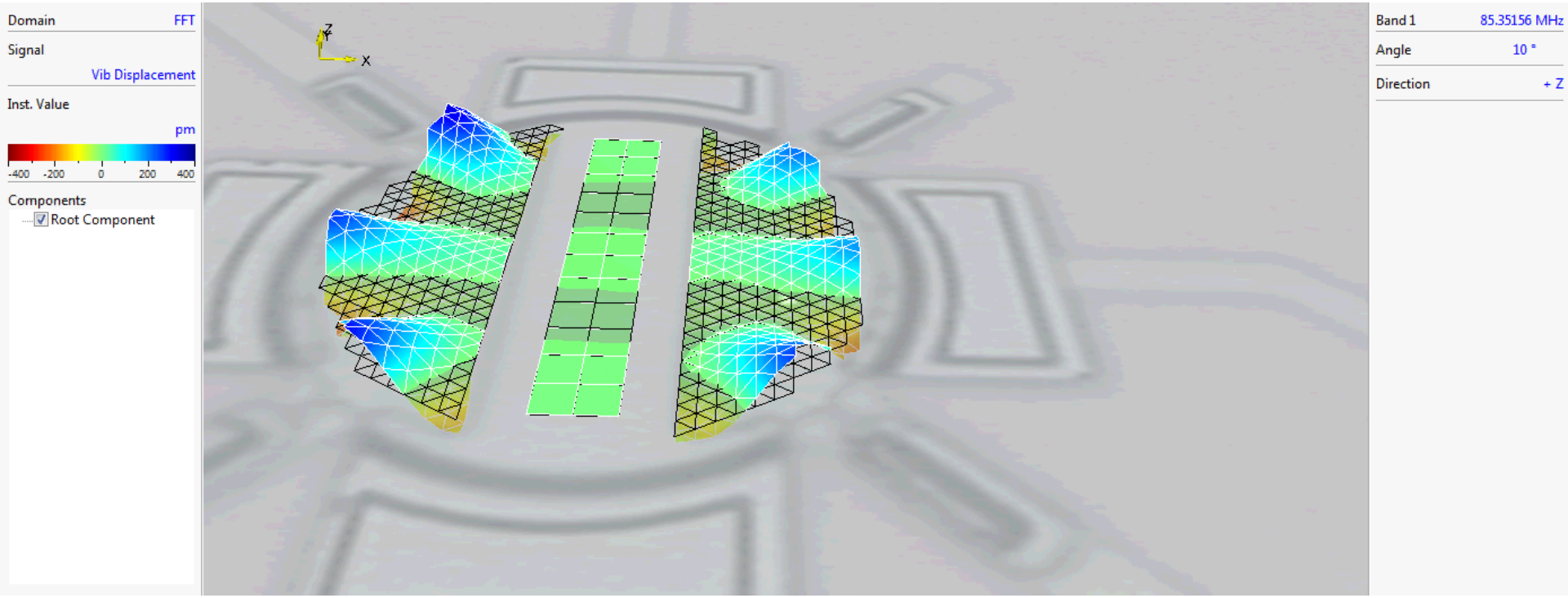




Courtesy Dr. Clark Nguyen, BSAC

- **Vibrating Micro Mechanical Resonator**
- Designed for use as on-chip **high-Q resonators** used in wireless communication systems for **frequency generation** and **filtering**.
- Utilizes a **wine-glass** resonant mode at 61.13 MHz
- **High Q factor** (>10,000 in air)

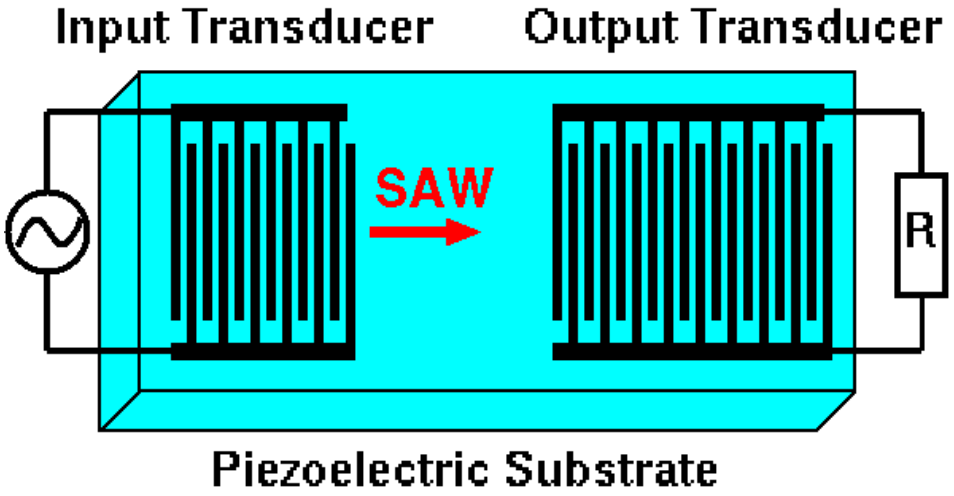
RF-MEMS Resonator



Courtesy Dr. Clark Nguyen, BSAC

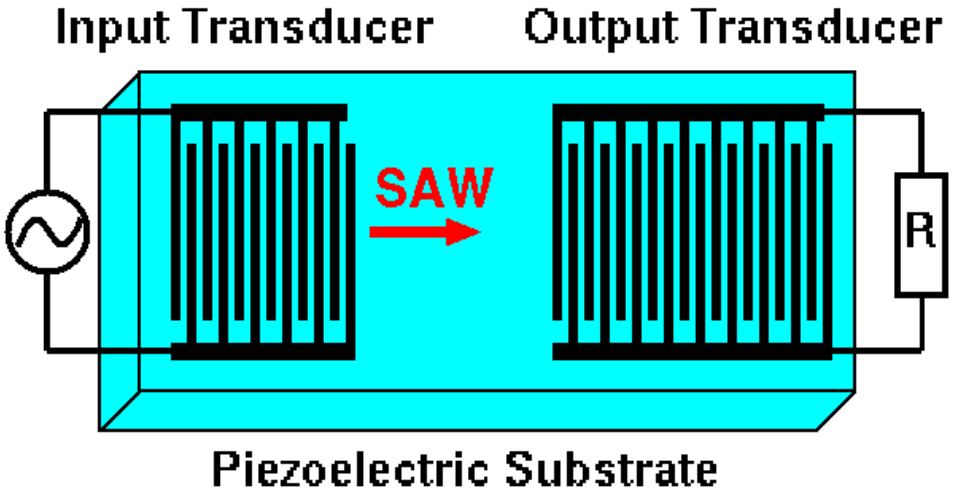
- Scan measurement of higher frequency mode at 85.35 MHz

Surface Acoustic Wave Filter



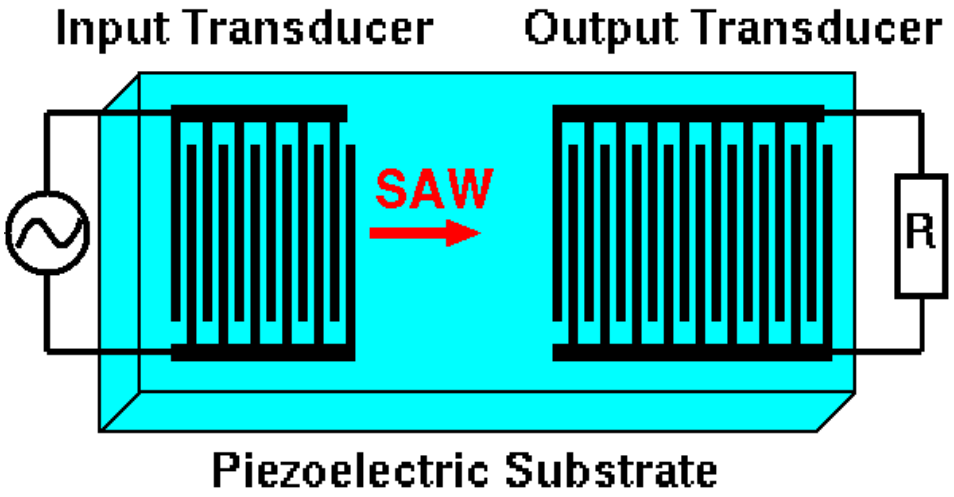
- SAW devices are used as filters, oscillators and transformers, devices that are based on the transduction of acoustic waves.
- The transduction from electric energy to mechanical energy (in the form of SAWs) is accomplished by the use of piezoelectric materials.

Surface Acoustic Wave Filter



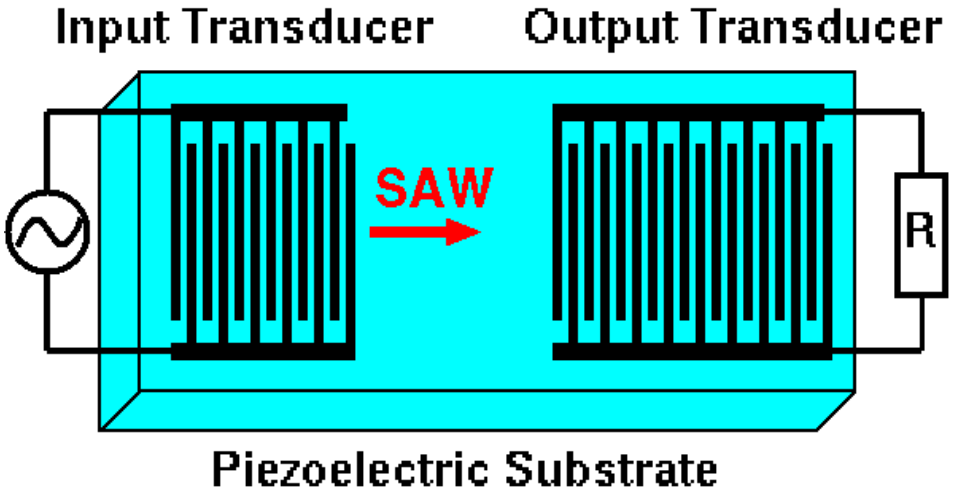
- SAW filters are used e.g. in mobile phones, and provide **significant advantages** in
  - **performance,**
  - **cost, and**
  - **size**

Surface Acoustic Wave Filter



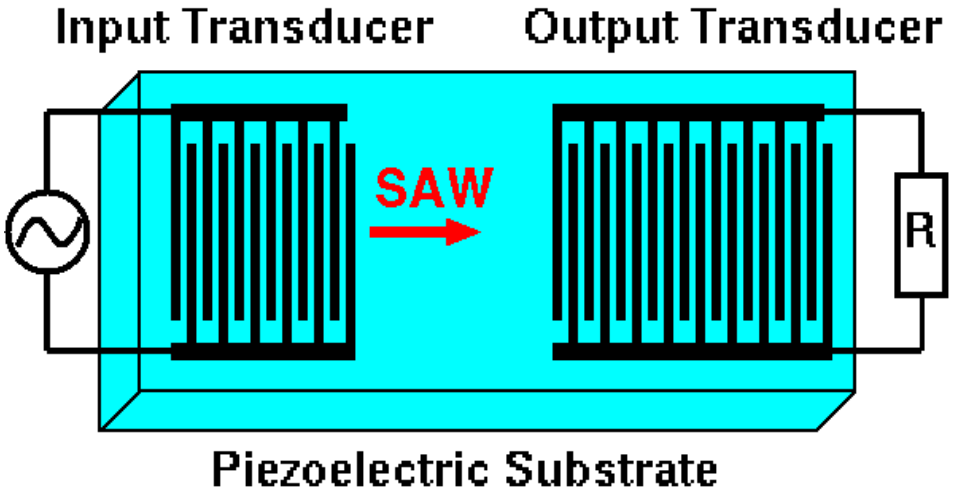
- HF Bandpass filter for electrical signals < 3 GHz
- Low transmission bandwidth
- Applications
  - HF transmitter and receiver: e.g. ISM, WLAN, GSM, …
  - Intermediate frequency filter in mobile phones etc.

Surface Acoustic Wave Filter



- **Electrical input**
  => Conversion in **S**urface **A**coustical **W**ave
  => Filtering with specific characteristic
  => Conversion in electrical Output signal
- **Specific electrical output**

Surface Acoustic Wave Filter



- **Challenges for Measurement:**
  - Very high frequency ⇨ **High measurement bandwidth**
  - High Q value ⇨ **High frequency resolution**
  - Short acoustical wavelengths ⇨ **High lateral resolution**
  - Small displacements ⇨ **Low noise**

Surface Wave Propagation

Leibniz-Institut
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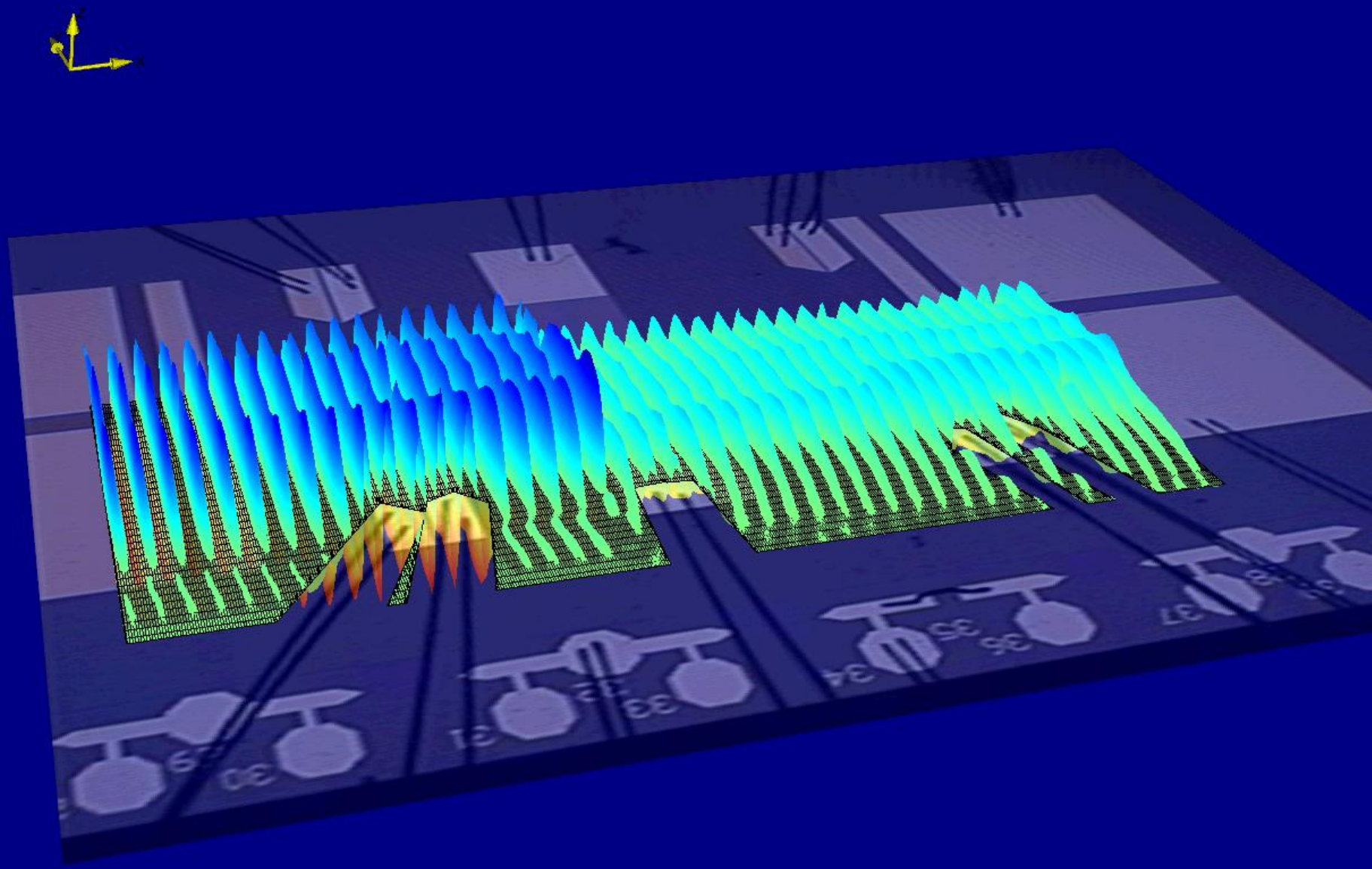
Werkstoffforschung
Dresden

Polytec



Surface Wave Propagation

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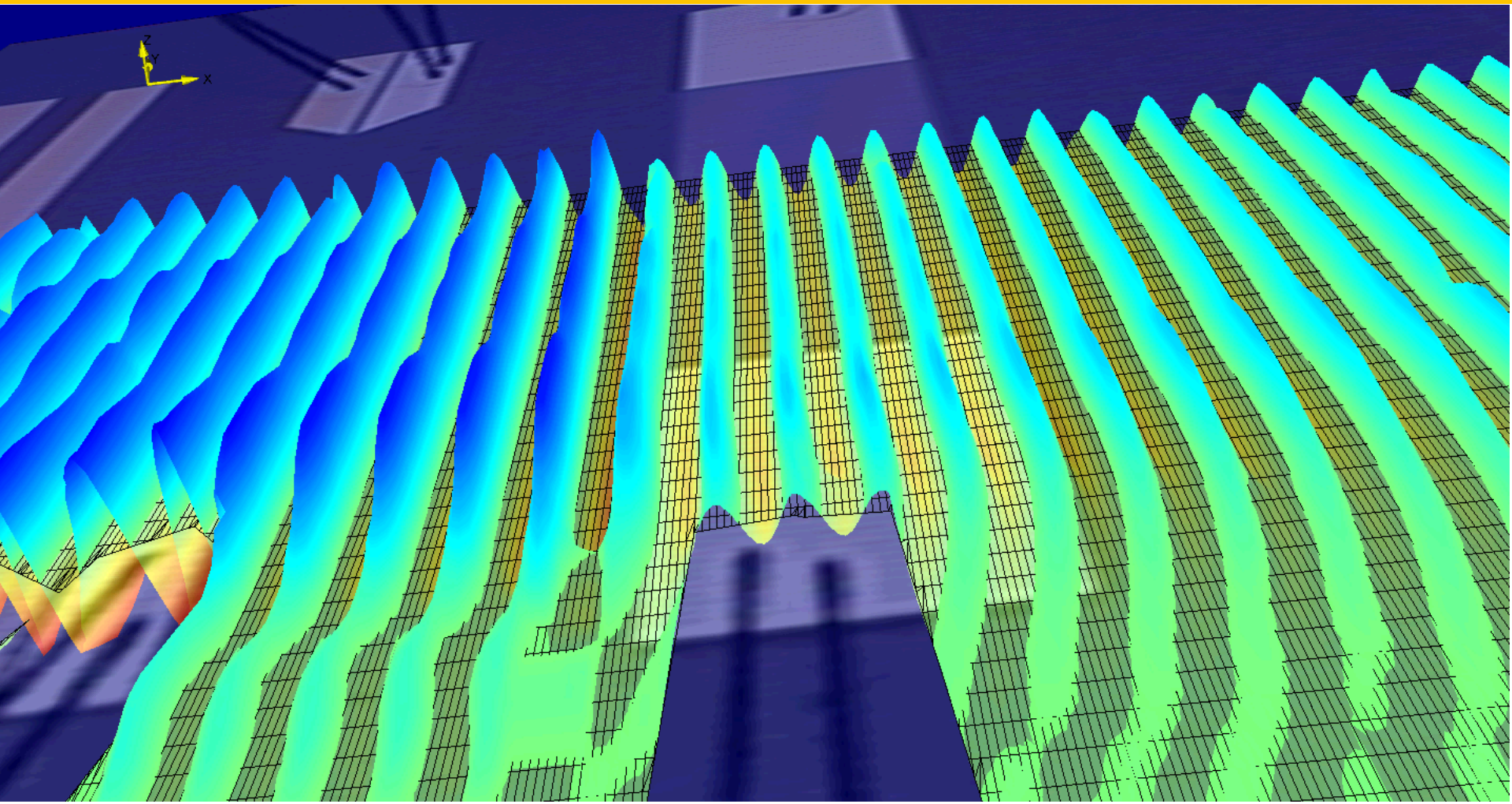

Surface Wave Propagation (Detail)

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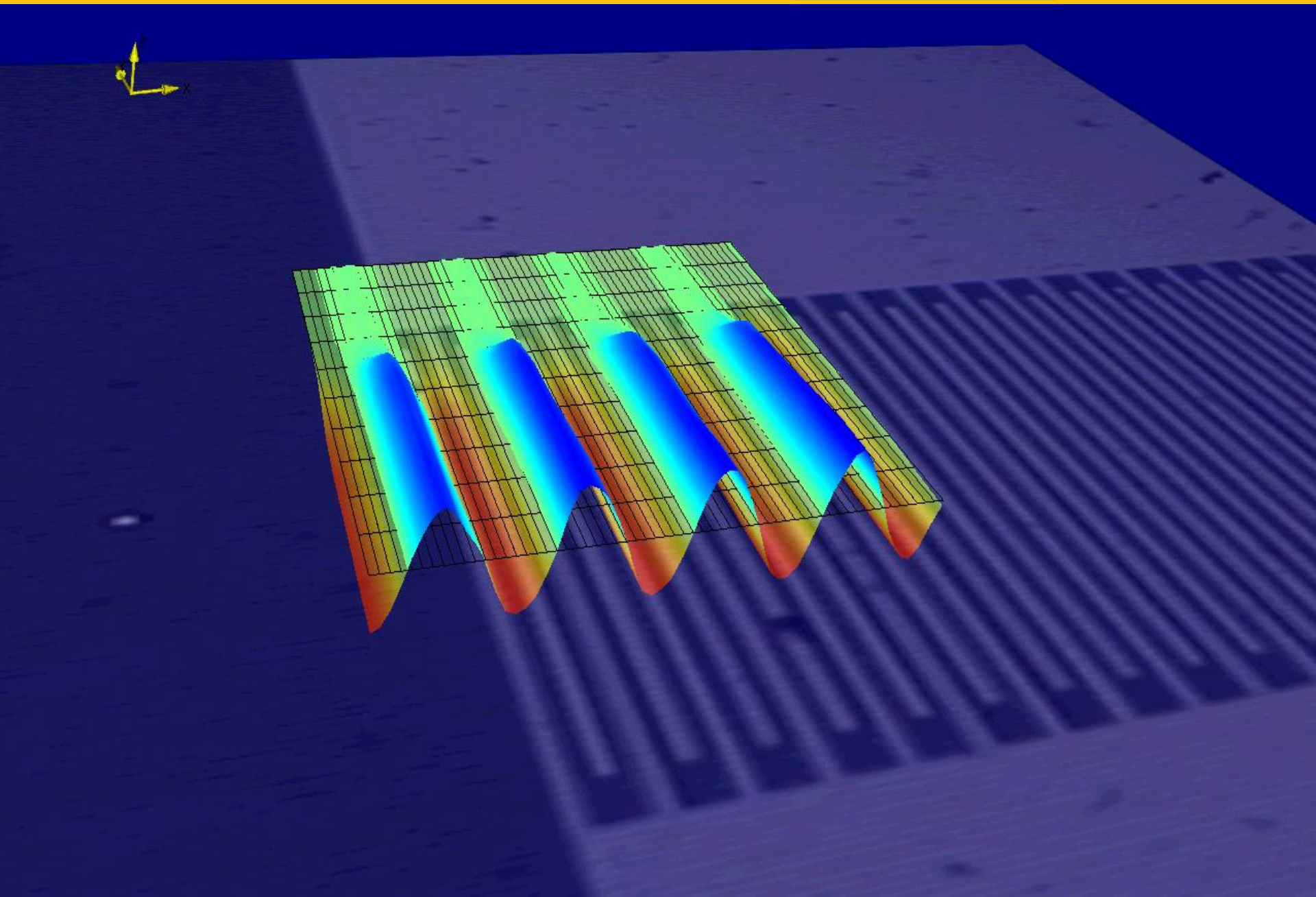
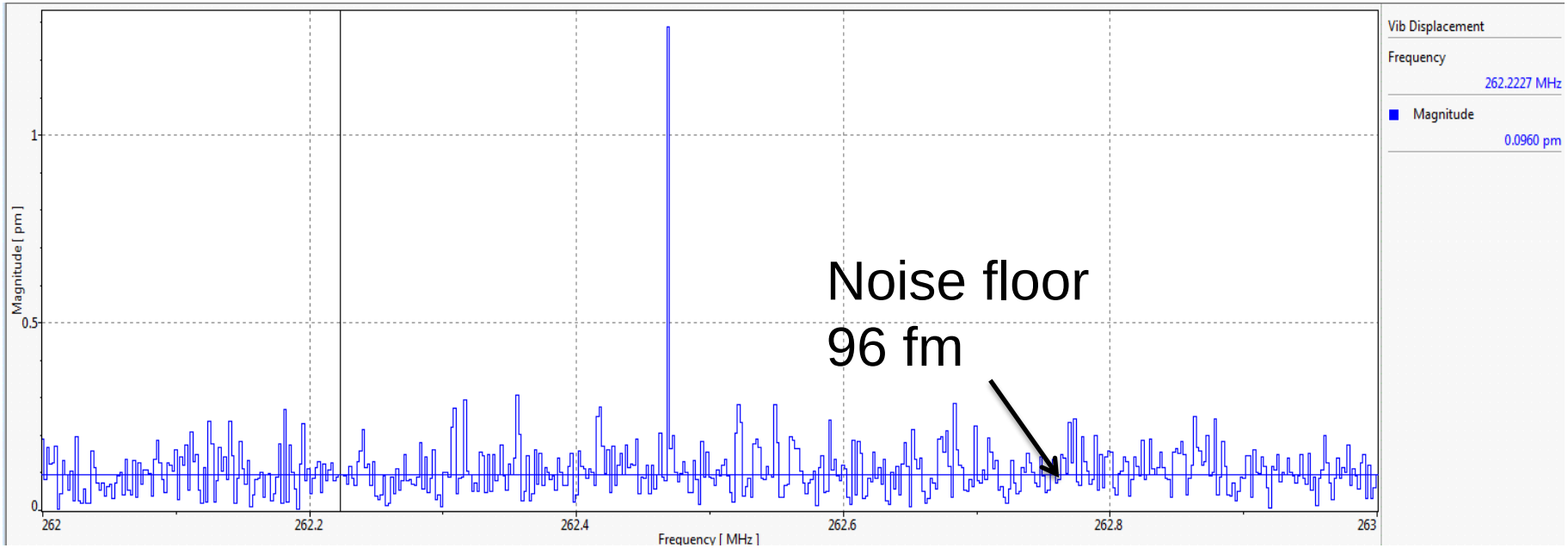


Sensitivity: SNR-Ratio

SAW-Filter response after narrowband excitation



Noise floor reduction by complex averaging

Application: Medical Imaging

- Transducers for ultrasonic frontend devices in medical diagnostics

Application: Medical Imaging

- Abdominal imaging, cellular imaging and measuring surfaces.
- The aim is to determine the 3-dim sound field dispersion in space by measuring the out-of-plane vibration of the components.
- Transducer Array: By selecting the correct amplitude and phase for each array element, it is possible, for example, to generate a focused ultrasonic wave

Ultrasound Transducer Array

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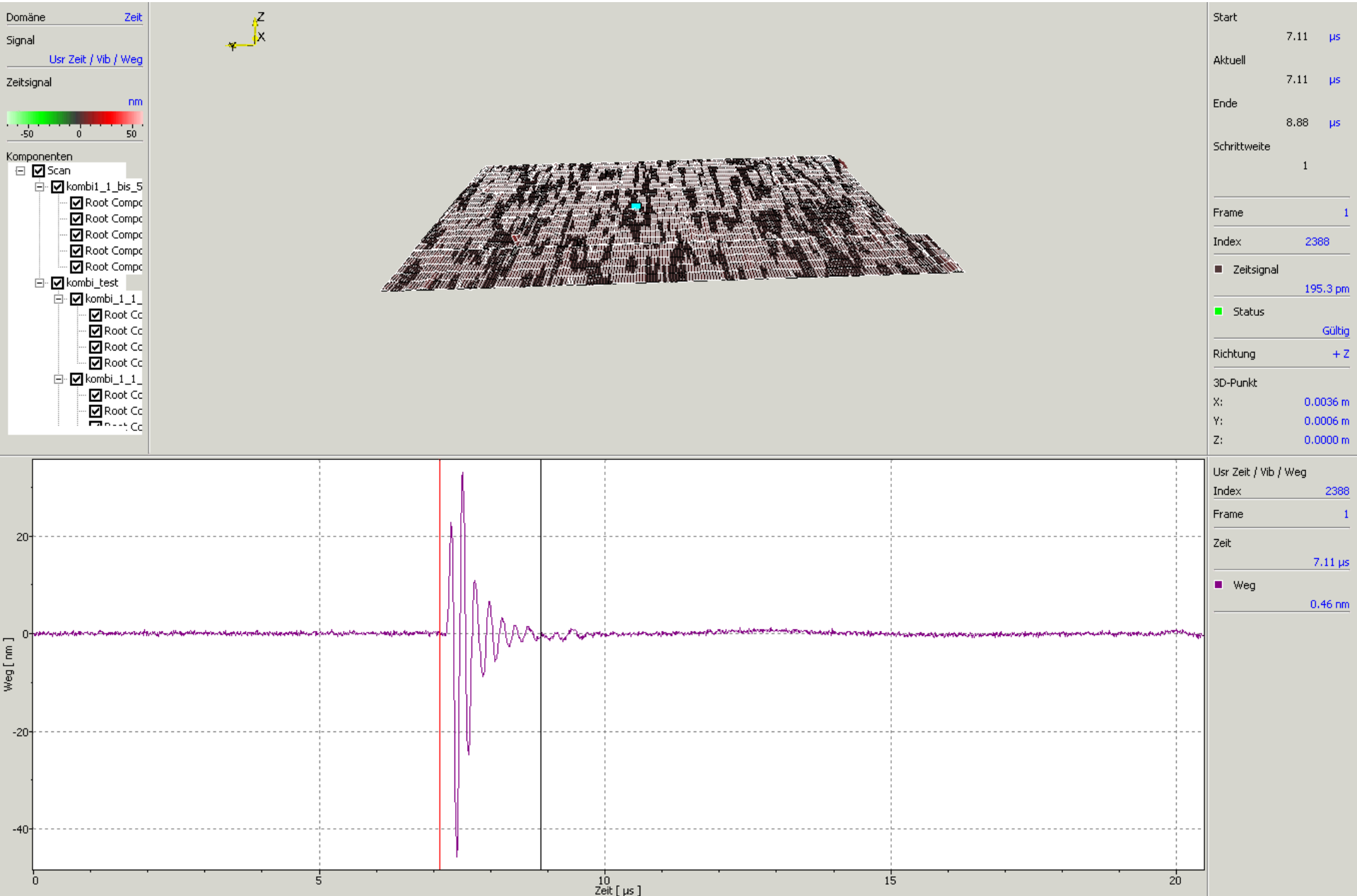
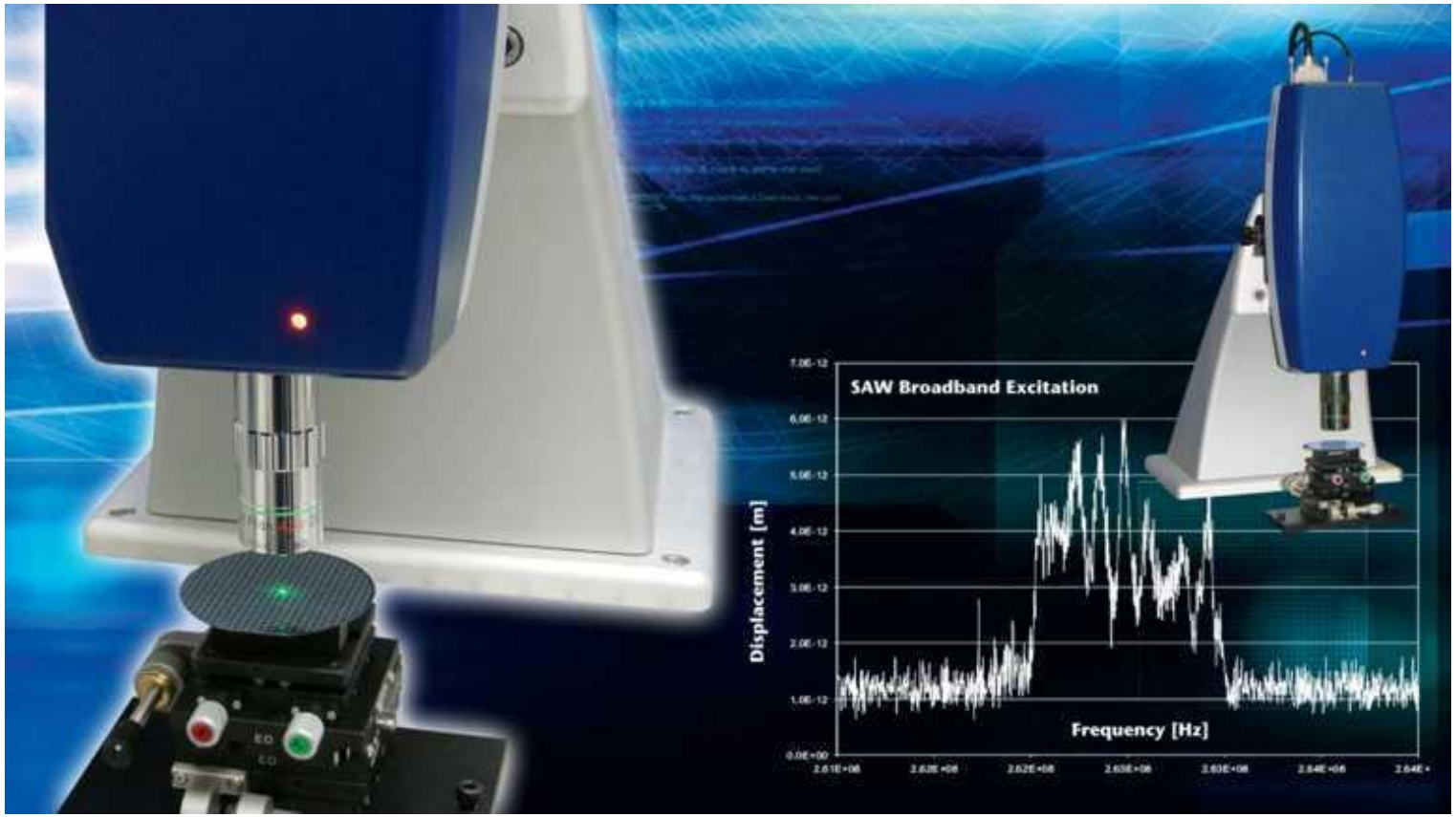
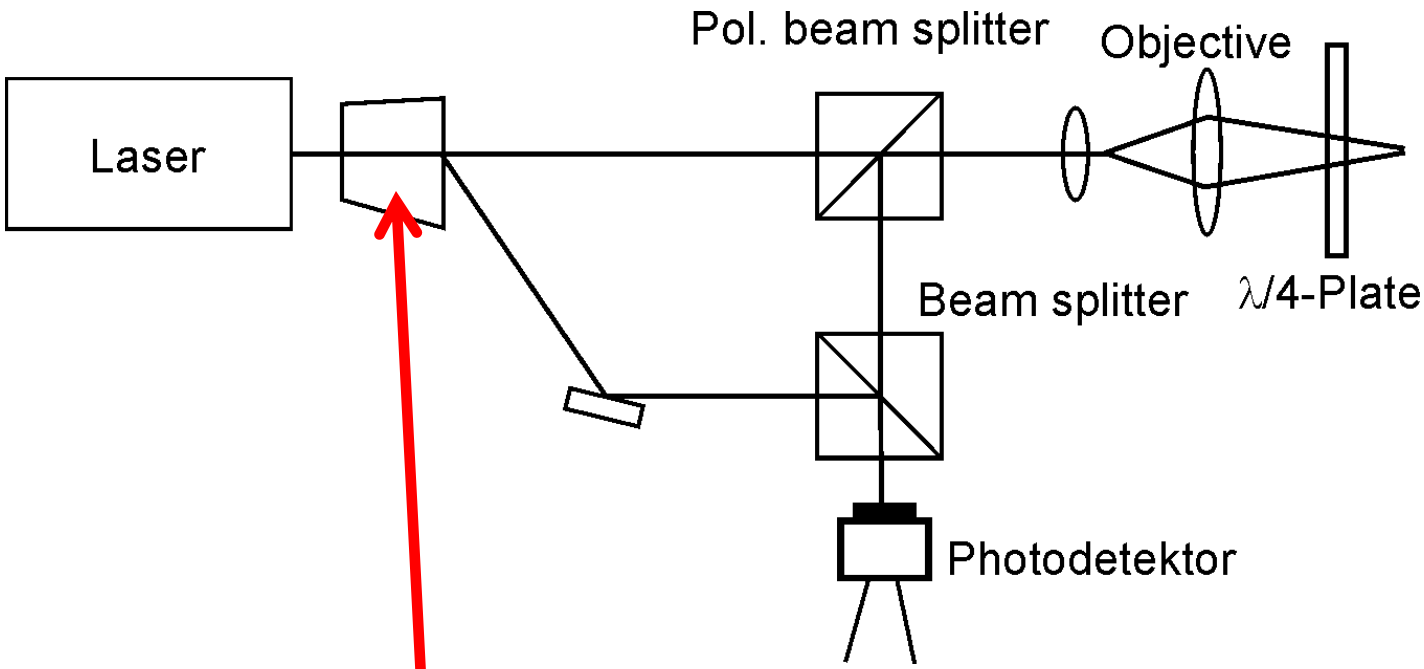


The UHF-120-SV Ultra-high Frequency Scanning Vibrometer



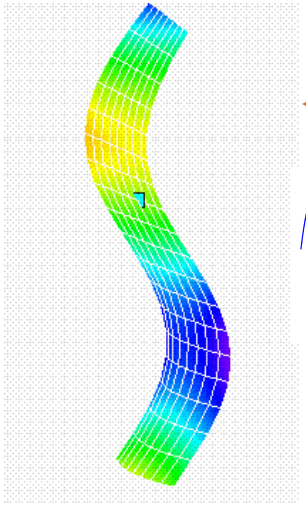
Optical Setup



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

Operation Principle

object



$\vec{v}$

meas. beam

scattered light

Laser

Interfero-
meter

reference beam

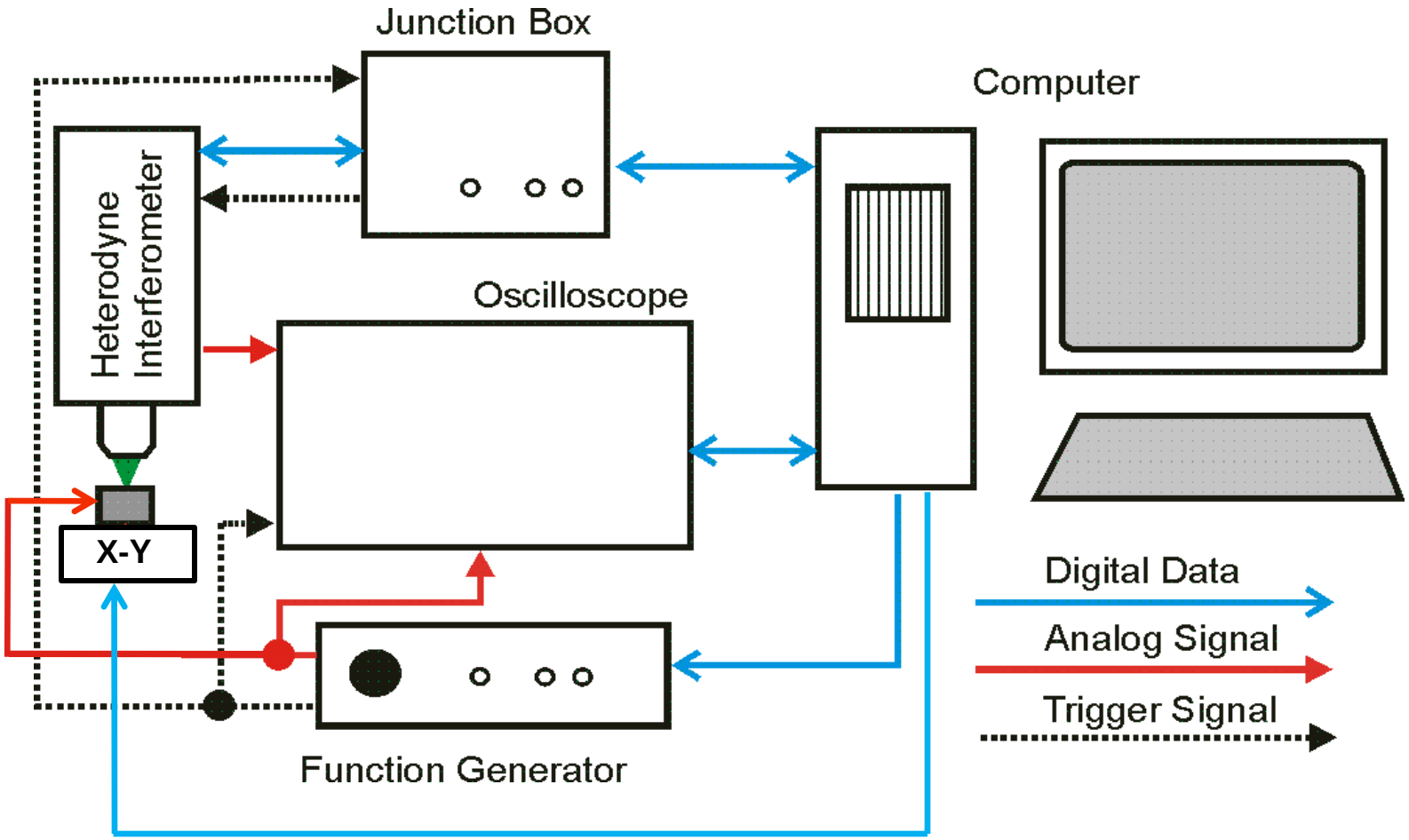
$$f_D = 2 \cdot \frac{v}{\lambda}$$

Doppler shift of laser frequency

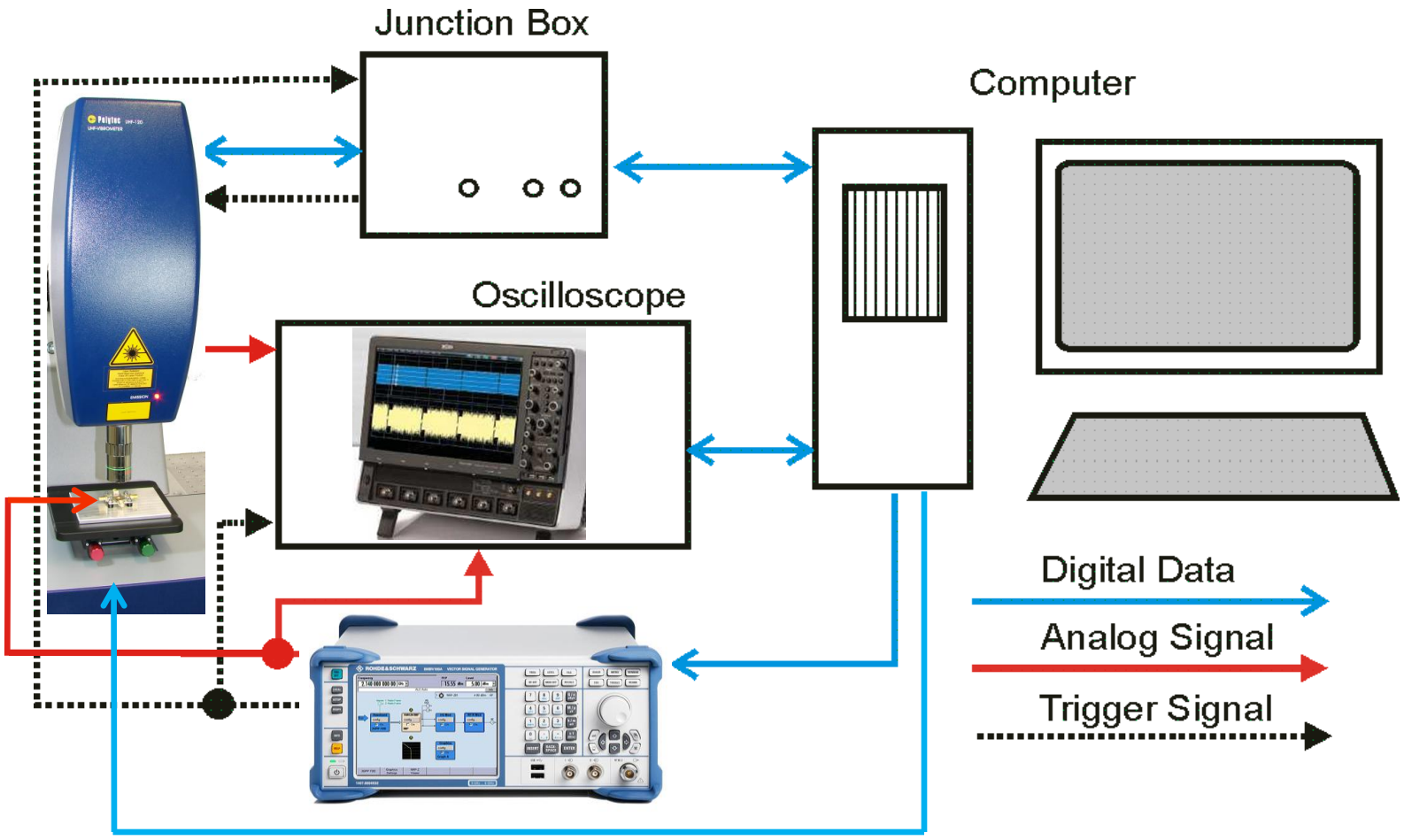
Detector

Interference signal frequency modulated

Components

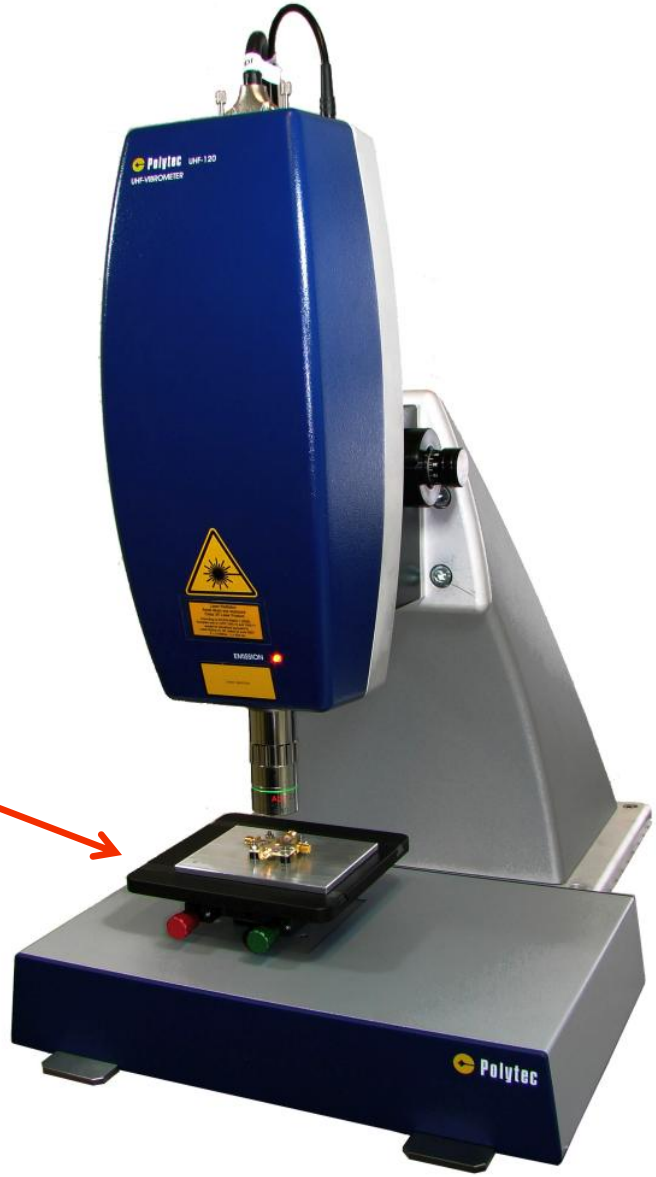

Junction Box
Computer
Heterodyne Interferometer
Oscilloscope
X-Y
Digital Data
Analog Signal
Trigger Signal
Function Generator

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



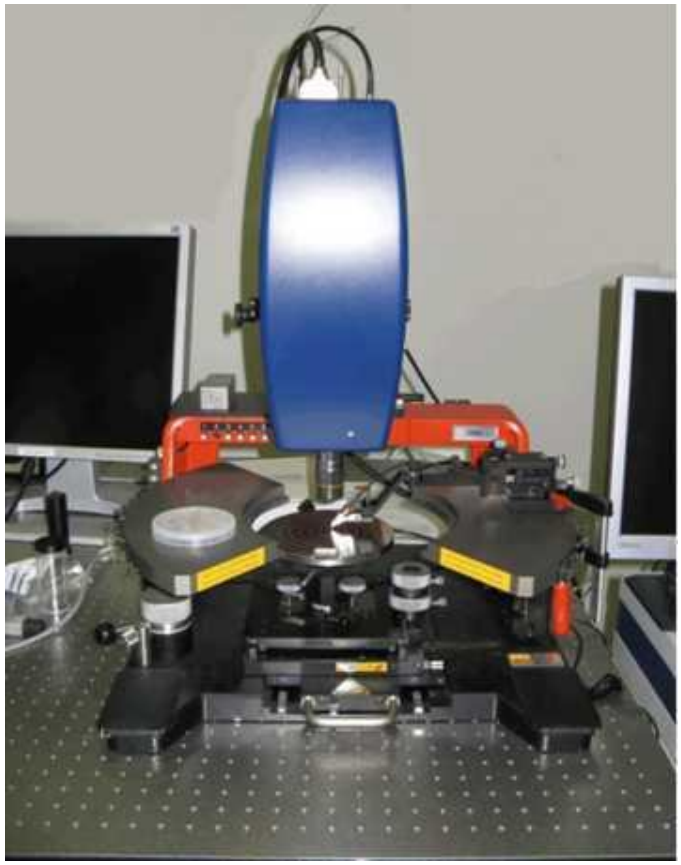
Laser Spot Size

- Speed of sound for silicon ~ $2.2*10^3$ m/s, => acoustical wave length at 1 GHz ~ 2.2 µm.

- => Spot size < 1 µm is realized to enable measurements up to 1.2 GHz at a specific equal deflecting sample point

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



Summary

- Studying UHFmechanical motion is a subject with increasing importance in many high tech application fields
- Precise measurement data are the key to fast prototype characterization and efficient device development
- Optical methods like Laser Vibrometry deliver unique measurement capabilities

Company Portrait

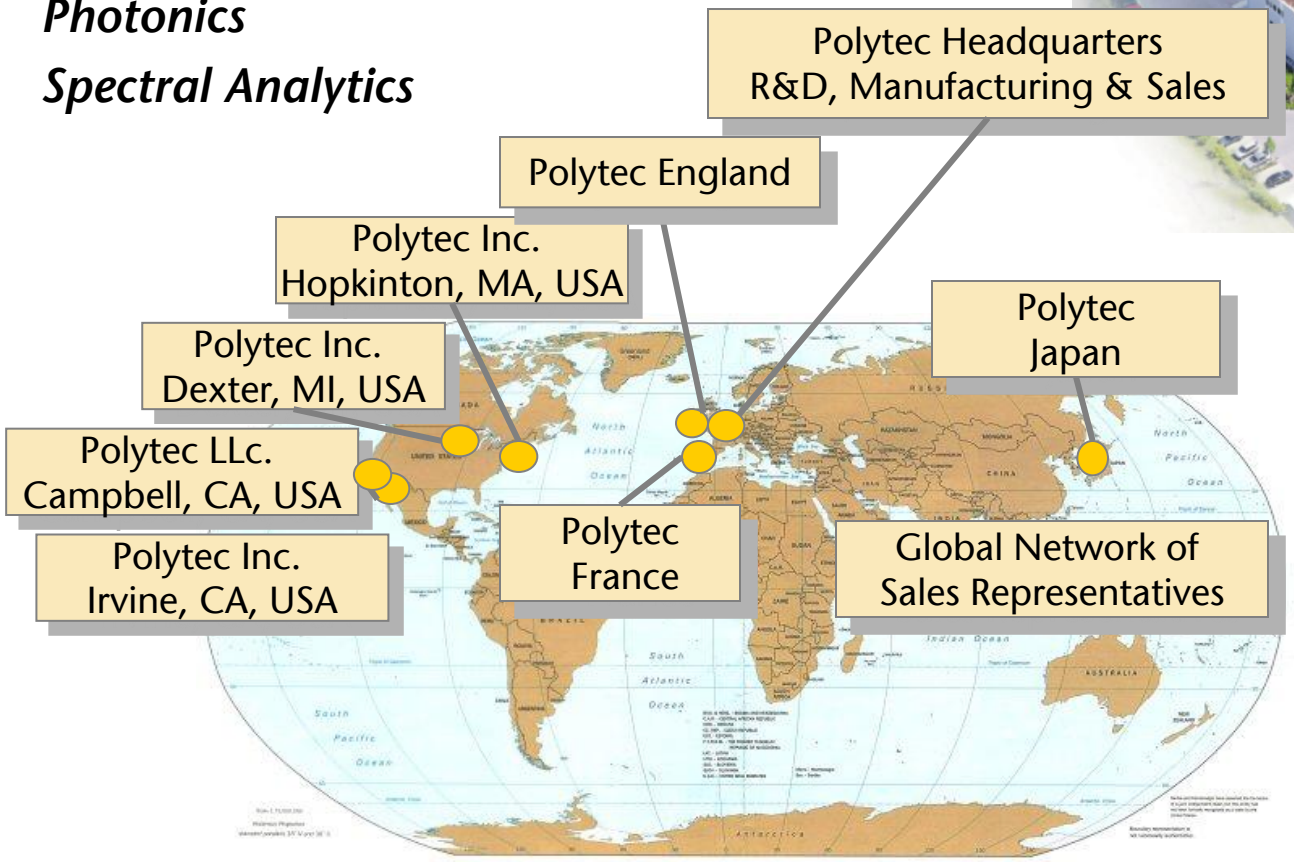
Business Units

Optical Measurement Systems

Photonics

Spectral Analytics

1967 Foundation



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