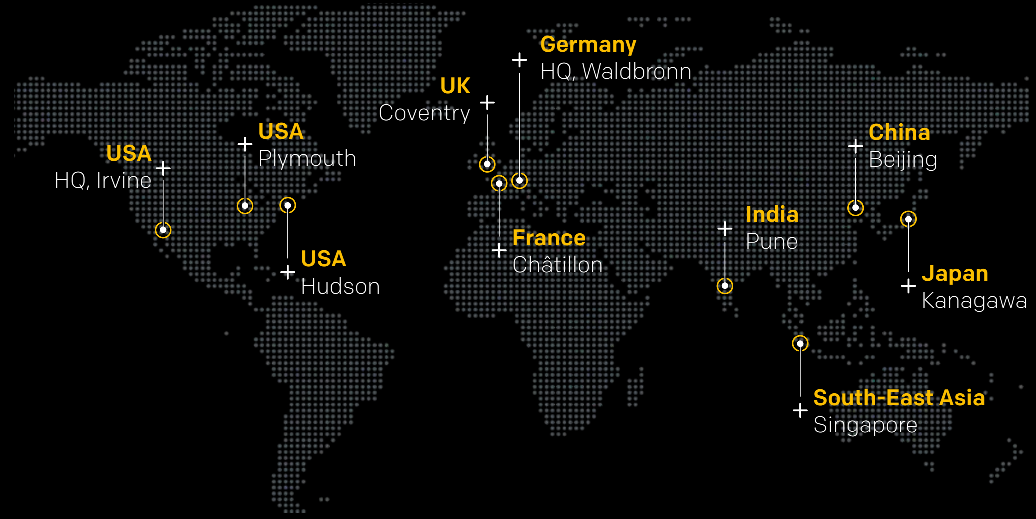

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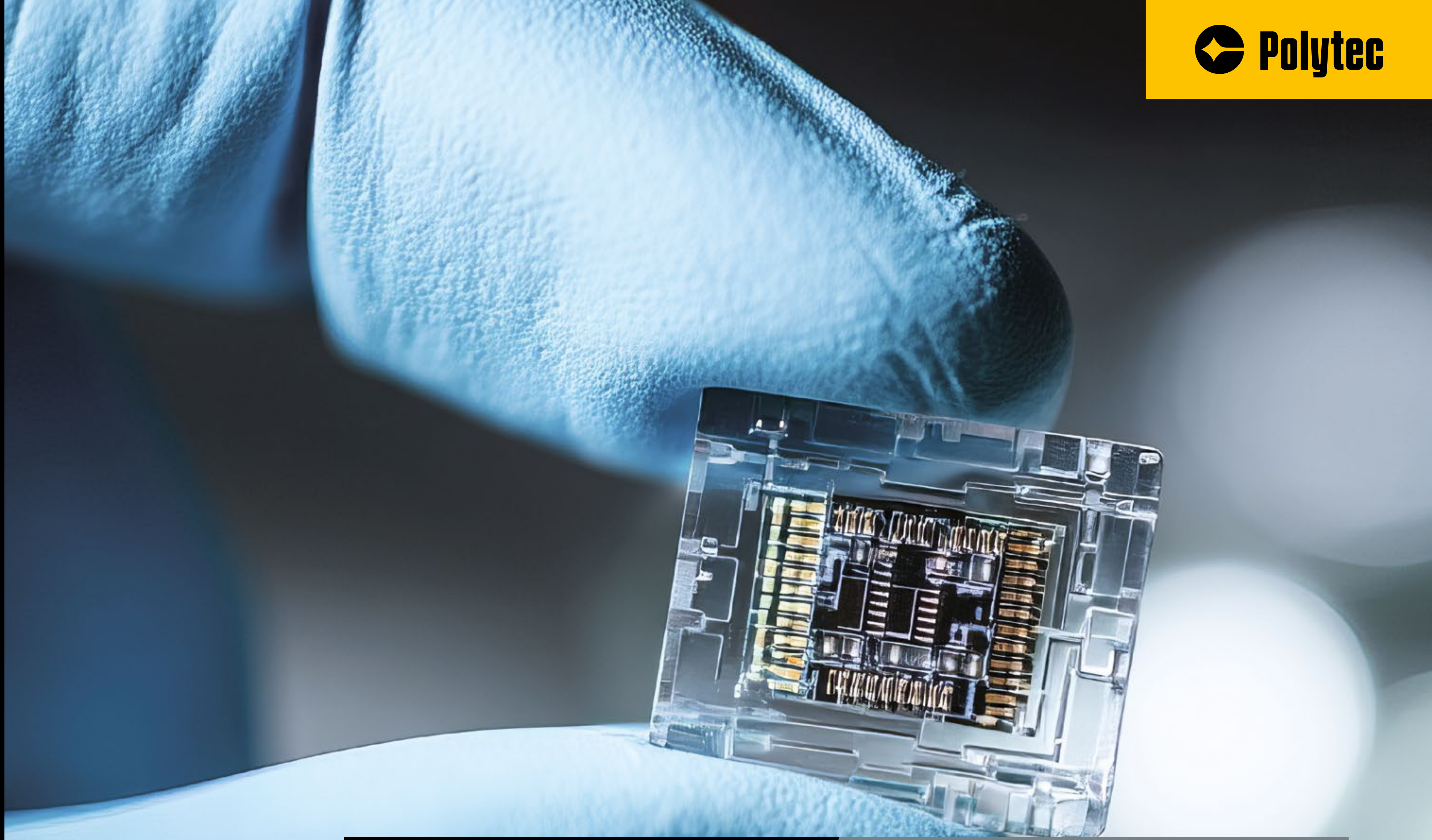


Polytec

Application //

Non-contact vibrometry for meso-components and microstructures

polytec.com

1 MEMS microphone

The characterization of dynamic properties of meso-components and microstructures poses a major challenge for measurement technology due to their dimensions. Meso-components, defined as small structures in the mm^2 range, usually embedded within larger systems, include critical components such as:

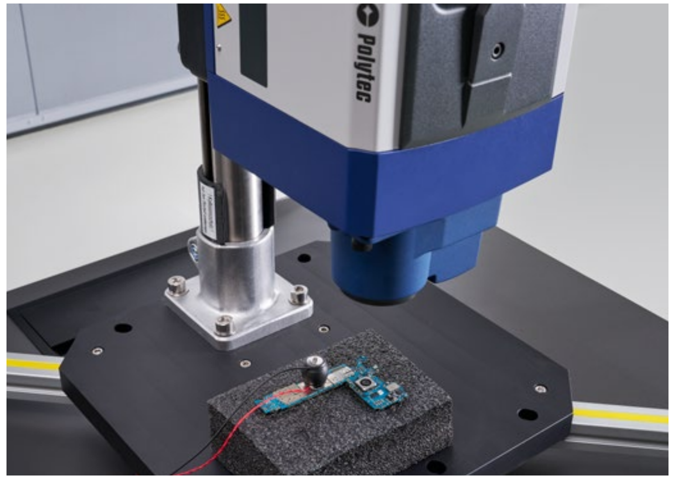
// Camera modules in smartphones
// Sensors and actuators on printed circuit boards
// Connecting elements such as bonding wires
// Larger MEMS or MOEMS components outside the microscopic range
// Biological structures such as insects or insect parts
// Hearing aids (external or implantable)
// Surgical instruments such as ultrasonic tips and blades

Optics for meso applications //

Scanning laser vibrometers, such as the VibroScan QTec, are designed as universal full-field vibrometers that are optimized in their basic optical configuration for measuring objects in the cm^2 to m^2 range. With suitable additional optics, the scanning range can be extended into the meso and micro ranges.

CLOSE-UP UNIT (COAXIAL UNIT)

The PSV-A-X10 Close-up Unit enables parallax-free measurements with LED ring light for good contrast. Additional micro-scan lenses reduce the spot size and ensure good magnification. A special feature is that they ensure an almost parallel beam path, which is mandatory for reflective surfaces, as an obliquely incident beam causes the light to be reflected away from the collecting optics. The achievable spot sizes range from 8.4 µm (Neo) to 36 µm (Xtra).



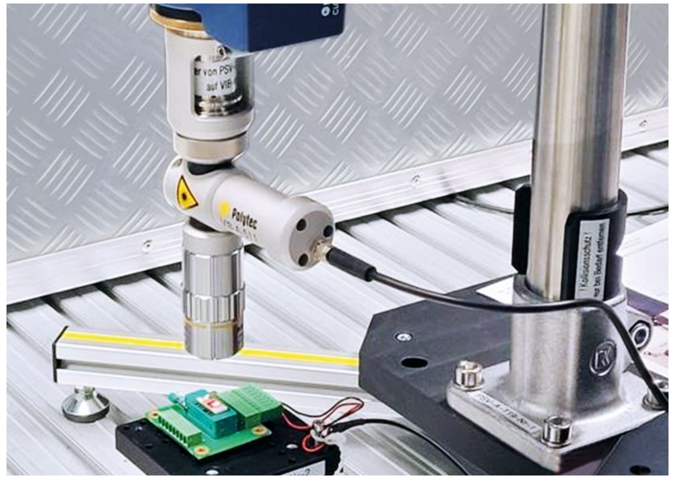
2 Measurement of camera module with close-up unit

MICROSCOPE EXTENSION

A microscope extension is available for maximum spatial resolution. It complements the close-up unit, further increases the magnification, but limits the scan range and measurement field. It features coaxial LED illumination for the best possible image quality and allows the use of microscope objectives with different magnifications and high numerical apertures. The achievable spot size is less than 2 µm at 10x magnification, enabling the characterization of even the smallest structures.

Spot sizes below

// 2 µm



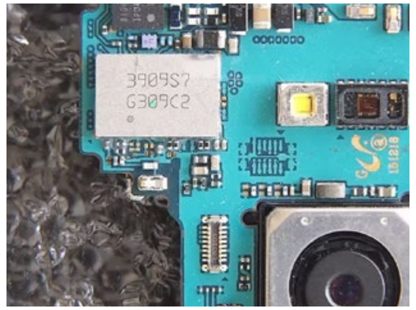
3 MEMS cantilever measurement with microscope extension

Technical specifications //

Parameters	Close-up Unit PSV-A-X10			Microscope lens			
Laser type	Neo		Xtra	Neo		Xtra	
Magnification	PSV-A-CL-Neo-125	PSV-A-CL-Neo-200	PSV-A-CL-Xtra-200	5x	10x	5x	10x
Spot size [µm]	8.4	13.5	36	<4	<2	<8	<4
Depth of field [µm]	90	220	650	~17	~5	~40	~12
Working distance [mm]	206	282	282	34*	34*	34*	34*
Field of view Ø [mm]	21	33	33	~2	~0.9	~2	~0.9

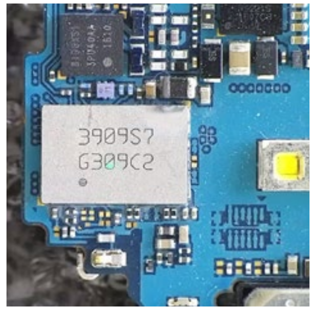
* Working distance to microscope lens

A Measured object without additional optics (optimal camera zoom)



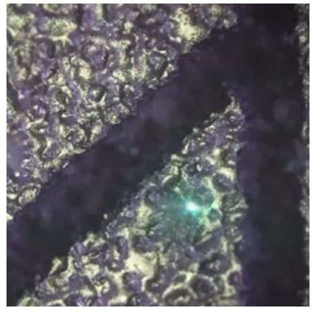
B Maximum camera zoom and close-up lens

C Close-up unit for parallax compensation (optimal camera zoom)

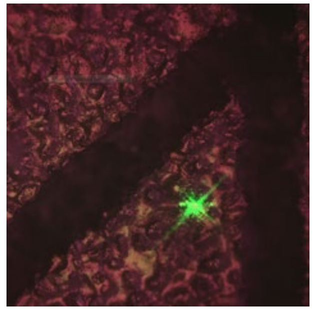


D Close-up unit with micro-scan lens

E Close-up unit with 5x microscope lens



F Close-up unit with 10x microscope lens



G Close-up unit with 10x microscope lens, high-contrast laser display on

Sample image for C - G

DEPTH OF FIELD AND LAYER DISCRIMINATION

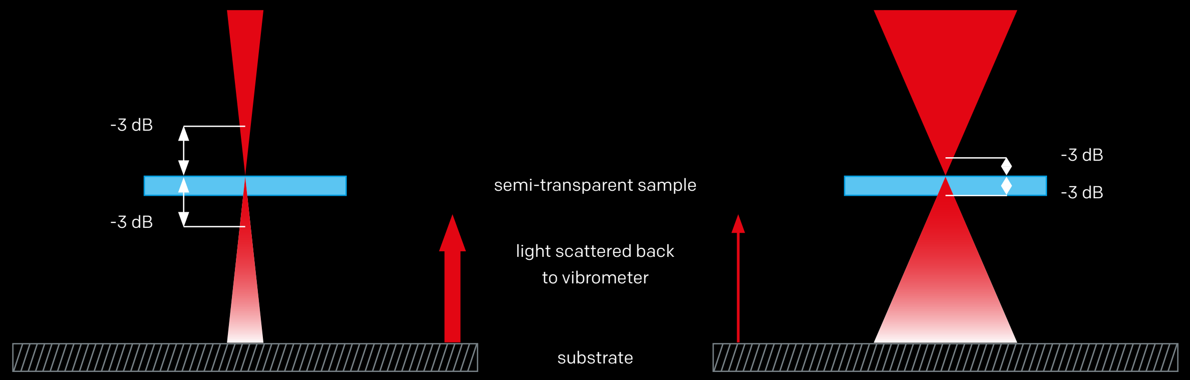
The choice of numerical aperture (NA) directly influences the measurement characteristics:

- Low NA:
  High depth of field, suitable for uneven surfaces
- High NA:
  Low depth of field, best discrimination of structures and substrate

In multi-layer samples, back reflections from the substrate reduce the signal-to-noise ratio and can influence amplitude measurements.

// Low NA – high depth of field

// High NA – low depth of field

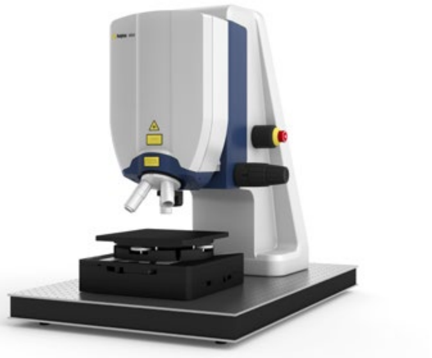


4 Relationship between numerical aperture and depth of field

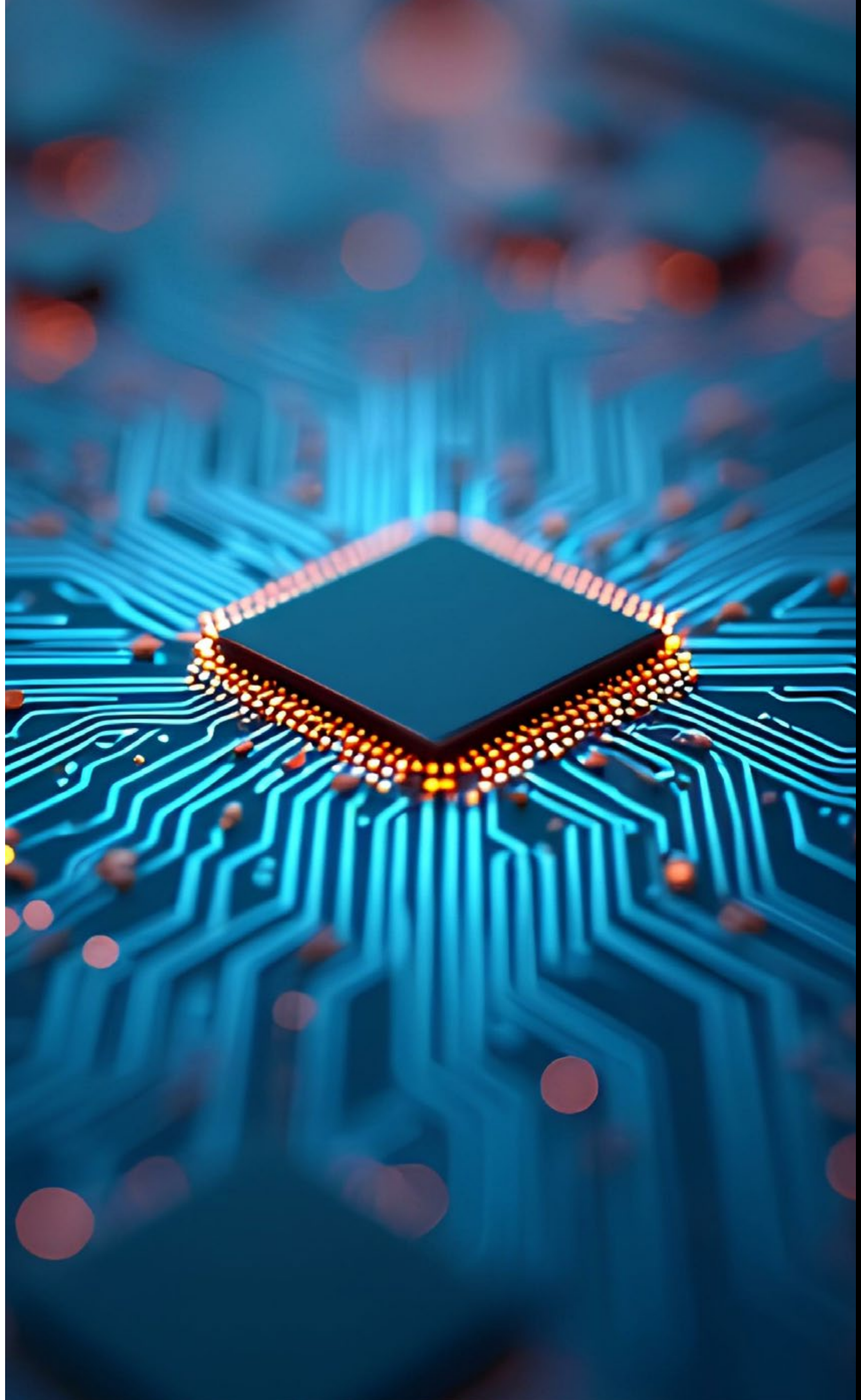
System comparison: VibroScan vs. Micro System Analyzer //

Parameters	VibroScan QTec	MSA-060/MSA-600
Max. field of view	several m^2	10×7 mm^2
Min. field of view Ø	~1 mm	~0.1 mm
Min. spot size	<2 µm	0.8 µm
Best spatial resolution	~2 µm	~200 nm

5 VibroScan QTec Neo on vertical test stand



6 MSA-600 Micro System Analyzer

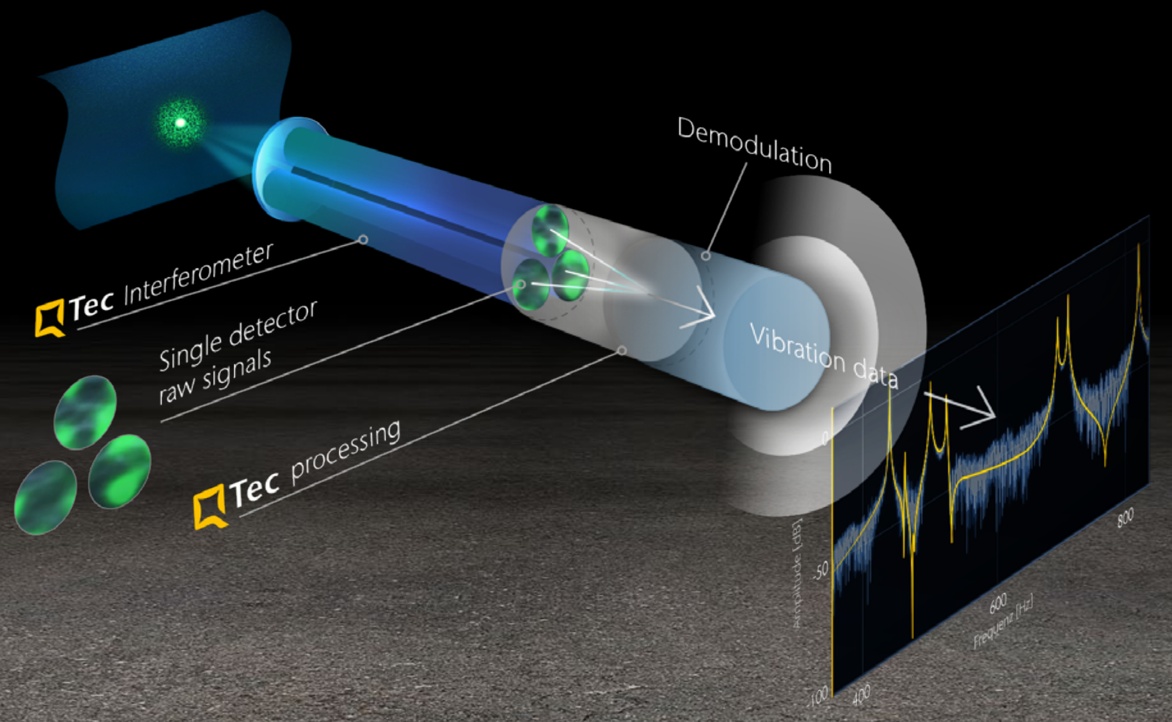


Software features for meso applications //

Small, often delicate structures and high magnifications require support from software tools in the operating software.

To precisely define and measure the measuring points, the integrated image processing system „High Contrast Laser Display“ is used. It generates a „virtual laser spot“ that eliminates glare effects on highly reflective surfaces, thereby providing good contrast even on challenging surfaces. Systems with pilot lasers (Xtra) are equipped with laser dimmers, whereas the measuring laser in gas lasers, such as the HeNe laser in the VibroScan QTec Neo, cannot be adjusted. The image processing shifts the solution into the software.

Advantages of non-contact laser Doppler vibrometry //



Highlights //

+ No influence on the measured object
+ High spatial resolution
+ Bandwidth up to 32 MHz (up to the GHz range with the dedicated Micro System Analyzer)

Optical vibrometry offers decisive advantages. Non-contact measurement eliminates mass loading effects and mechanical influence on the measured object. This enables verification of actual performance by measuring amplitudes, resonance frequencies and deflections without affecting the structure. The micrometer-sized laser spot enables the characterization of the finest structural details. With close-up units, VibroScan QTec Neo systems achieve spot sizes of 8.4 µm, while the microscope extension enables spot sizes of less than 2 µm.

This is accompanied by improved control of depth of field. By selecting the numerical aperture (NA), users can precisely adjust the depth of field—low NA for greater depth of field, high NA for better layer discrimination in multilayer structures.

The high spatial resolution in scanning measurements, together with the bandwidth of up to 32 MHz is also a prerequisite for the detection of high-frequency ultrasound modes.

Up to
// 32 MHz
bandwidth

Application examples from the macro, meso, and micro world //

VALIDATION STRATEGIES

The validation of dynamic simulation models is fundamental. In addition to resonance frequencies, the surface measurement also provides the operating vibration modes. Curve fitting methods can be used to determine the modal parameters, especially the damping/Q factor. MAC comparisons provide information about the quality of the correlation between the model and the test.

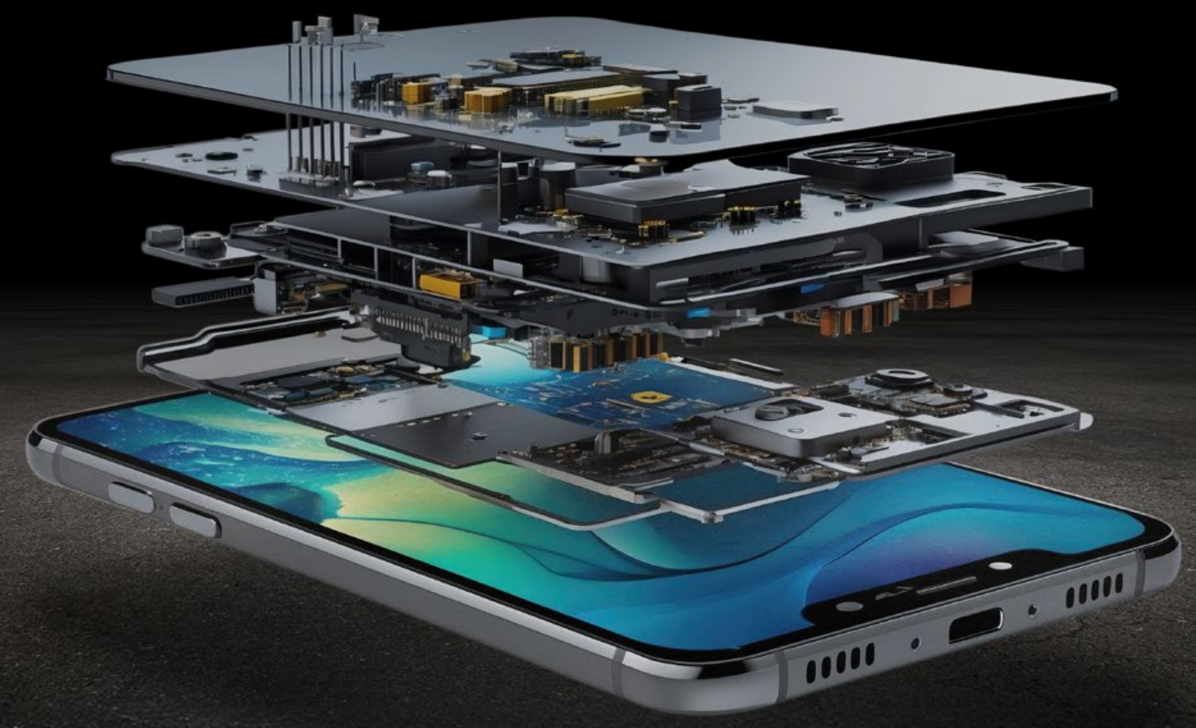
If actuators are involved, performance validation under operating conditions generally needs to be included. This allows deviations to be identified in advance. This includes measuring actual amplitudes and resonance frequencies under operating conditions, displacement measurements and checking the uniformity of actuator movements using time-displacement curves.

OVERVIEW OF APPLICATION AREAS

The goal is to use a single measurement system for all of these diverse tasks. In acoustics this includes questions such as the characterization of sound radiation or crosstalk between speakers and microphones within confined spaces. Elements for haptic feedback require either the determination of amplitudes or the distribution of amplitudes and wave propagation, for example in haptic displays. Motion analysis of actuators and sensors provides insight into the actual time-displacement behavior of actuating elements, such as focus drives.

Consumer electronics: Smartphone development in detail //

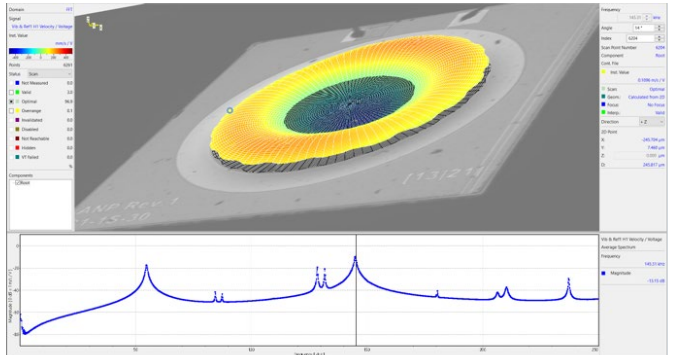
7 Smartphone components



The development of modern smartphones requires a variety of vibration analyses at different structural levels. The tasks mentioned here also apply to other devices with high integration density in the fields of medical or audio technology.

ACOUSTIC OPTIMIZATION

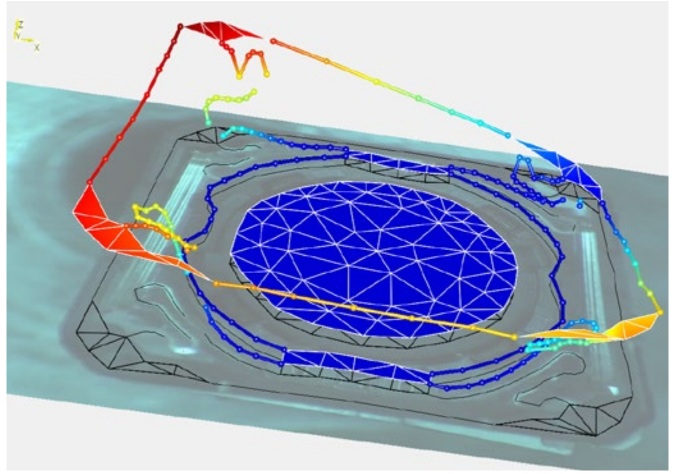
Good sound quality, whether when making phone calls or listening to music, is a noticeable quality feature. Measuring the acoustic coupling between loudspeakers and microphones as well as camera modules (crosstalk) provides valuable information, as does the identification of electromagnetically induced noise (see „Singing Capacitor" below). Components such as (MEMS) loudspeakers or cantilever microphones are also part of the vibration characterization process, both on the manufacturer's side and on the integrator's side. Installation in the final product can significantly alter their behavior in some cases.



8 Vibration mode of a MEMS microphone. Diameter approx. 1 mm

IMAGE STABILIZATION AND CAMERA SYSTEMS

The precise deflection, stabilization, and robustness of the camera's focus unit require special attention. Vibrations impair imaging performance and can also contribute to noise. FEM validation of the model, together with operational vibration mode analysis, contributes to faster convergence between performance and comfort requirements. The dimensions, especially of the suspension, require a small laser spot and a higher magnification. Excitation is provided by a shaker for modal analysis and by the actuator itself for motion analysis.



9 Vibration mode of a smartphone camera module

HAPTIC SYSTEMS

The sense of touch is very sensitive to vibrations, which is exploited in haptic feedback systems. Haptic motors are commonly used, where time sequence velocity measurements with sinusoidal excitation (typically 180 Hz) are used for validation. The fine laser beam comes so close to the contact surface of the finger that measurements under real conditions are possible for psycho-sensory research. A mostly macroscopic application that is particularly on the rise in the automotive sector is haptic displays that use traveling waves to simulate tactile impressions. Scanning laser Doppler vibrometers (SLDV) are used both for visualization and quantification of wave propagation, but also for subsequent quality assurance in production.

PRINTED CIRCUIT BOARD ANALYSIS: „SINGING CAPACITOR“

A common problem in smartphone development are the magnetostrictive forces of capacitors, which lead to audible noises. The circuit board acts as a „speaker,“ excited by the oscillating capacitor.

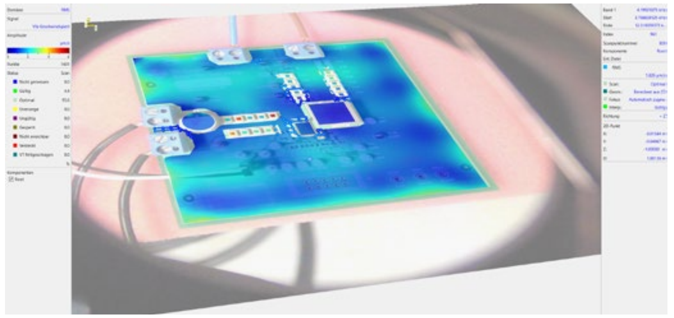
Measurement approach //

1. Localization of excitation sources:
   Scanning measurements identify vibration hotspots on the circuit board.

2. Frequency analysis:
   Microphone measurements reveal the sharp peaks of the monofrequency capacitor vibrations and their harmonics. This serves as evidence of acoustic radiation from the circuit board.

3. Structural analysis:
   ODS measurements characterize both the capacitor vibrations and the circuit board deformation. This allows design measures to be derived for design improvement.

This systematic analysis enables targeted design optimizations to reduce acoustic emissions.



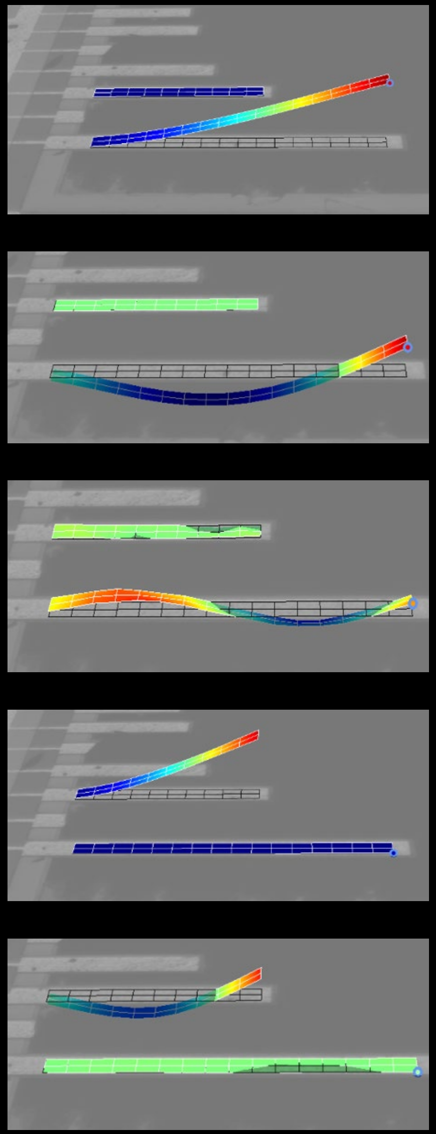
10 Excitation of a printed circuit board by capacitors

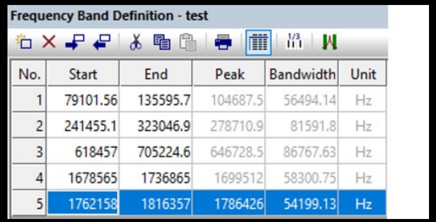
MEMS AND MICROMECHANICAL APPLICATIONS

In combination with close-up unit and microscope optics, even tiny components such as MEMS microphones, loudspeaker membranes or sensor elements can be measured with the highest resolution to visualize and quantitatively characterize vibrations, resonance behavior and frequency responses.

The benefits are particularly evident in the audio sector: the bending vibrations of cantilever microphones can be recorded precisely, enabling conclusions to be drawn about sensitivity and resonance optimization. Similarly, the micro-membranes of loudspeakers can be examined for their acoustic efficiency — a crucial step in the further development of compact audio systems.

The laser vibrometer is also an indispensable tool in sensor technology. This is where the transition to Micro System Analyzers (MSA) developed specifically for microsystem technology often begins. However, the structural sizes are often accessible also to VibroScan with the microscope extension. For acceleration sensors, it allows the behavior to be checked under defined excitations. Even magnetometers, whose susceptibility to interference from mechanical influences must be investigated, benefit from precise vibration analysis. Precisely because inertial measurement units combine a wide variety of sensor elements, optical measurement technology makes an important contribution to the overall evaluation here.

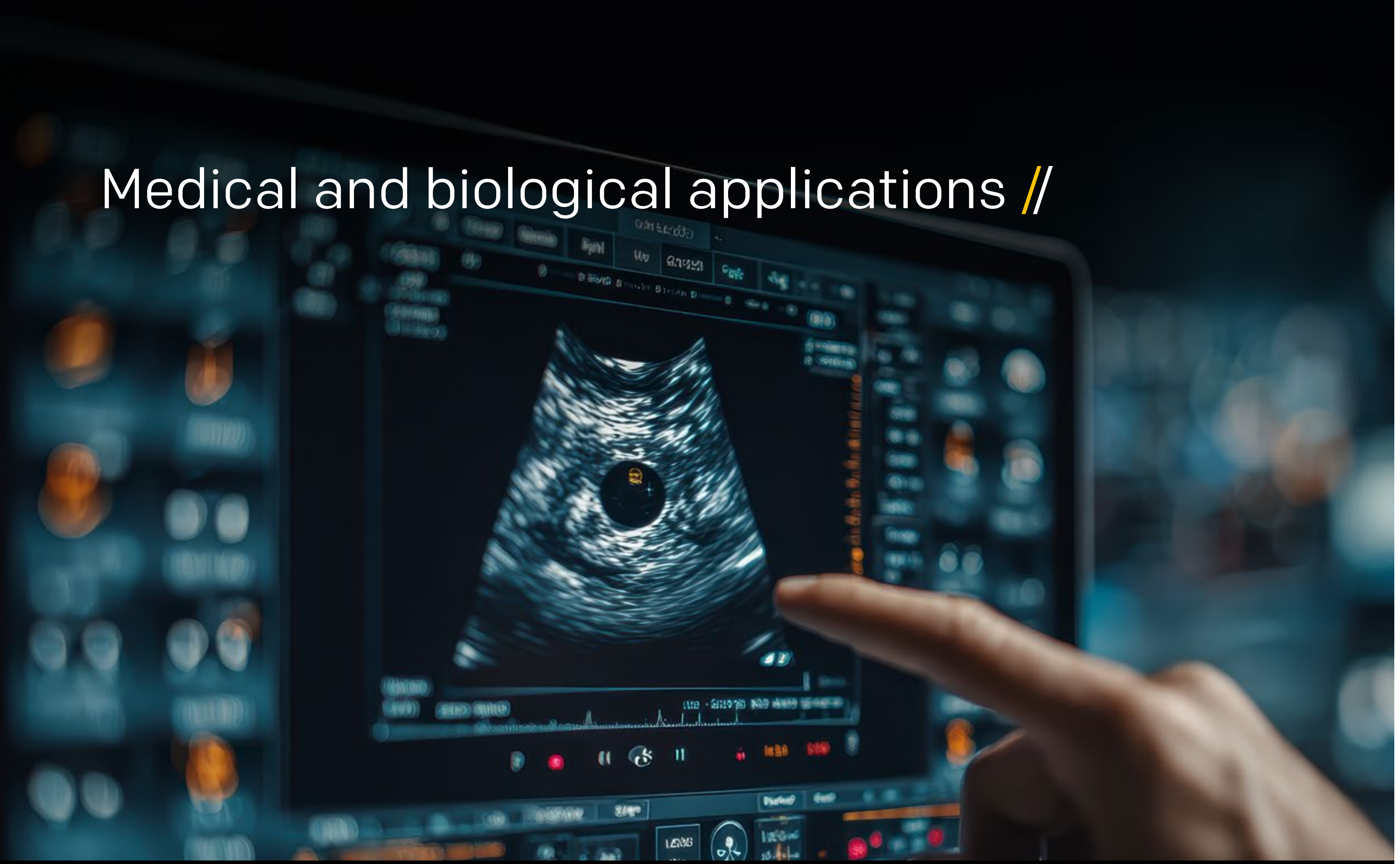



Frequency Band Definition - test

No.	Start	End	Peak	Bandwidth	Unit
1	79101.56	135595.7	104687.5	56494.14	Hz
2	241455.1	323046.9	278710.9	81591.8	Hz
3	618457	705224.6	646728.5	86767.63	Hz
4	1678565	1736865	1699512	58300.75	Hz
5	1762158	1816357	1786426	54199.13	Hz

11 MEMS cantilever with modes

Medical and biological applications //



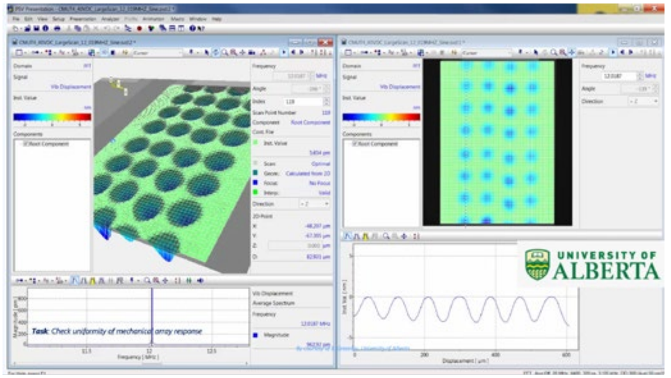
This area probably presents the widest range of challenges. It applies to materials, surfaces and measurement situations. The tool of choice is VibroScan QTec Neo with HeNe laser, which, in addition to its small laser spot, has the ability to measure through water, glass, and other transparent materials, enabling investigations in physiological environments.

ULTRASOUND TRANSDUCER

For medical ultrasound in diagnostics, cMUT and pMUT technologies have significantly reduced costs and size. The integration of the primary actuator into the actual transducer is one example where microstructures meet meso and macro-structures.

The typical tasks for transducers are:

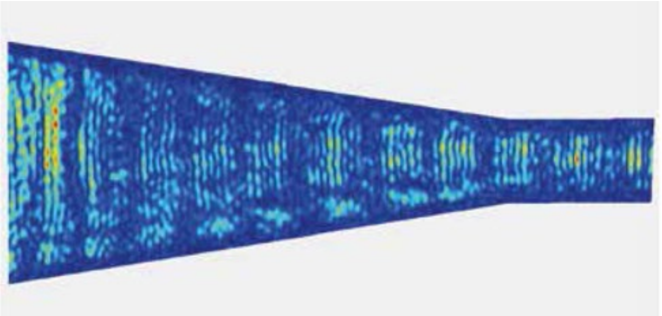
- CMUT arrays: Checking the uniformity of the mechanical array response during resonant excitation
- PMUT development: Timing analysis and crosstalk characterization between elements



12 CMUT transducer: Vibration mode shows uniformity of movement of individual elements, profile section on the right

MICROFLUIDICS

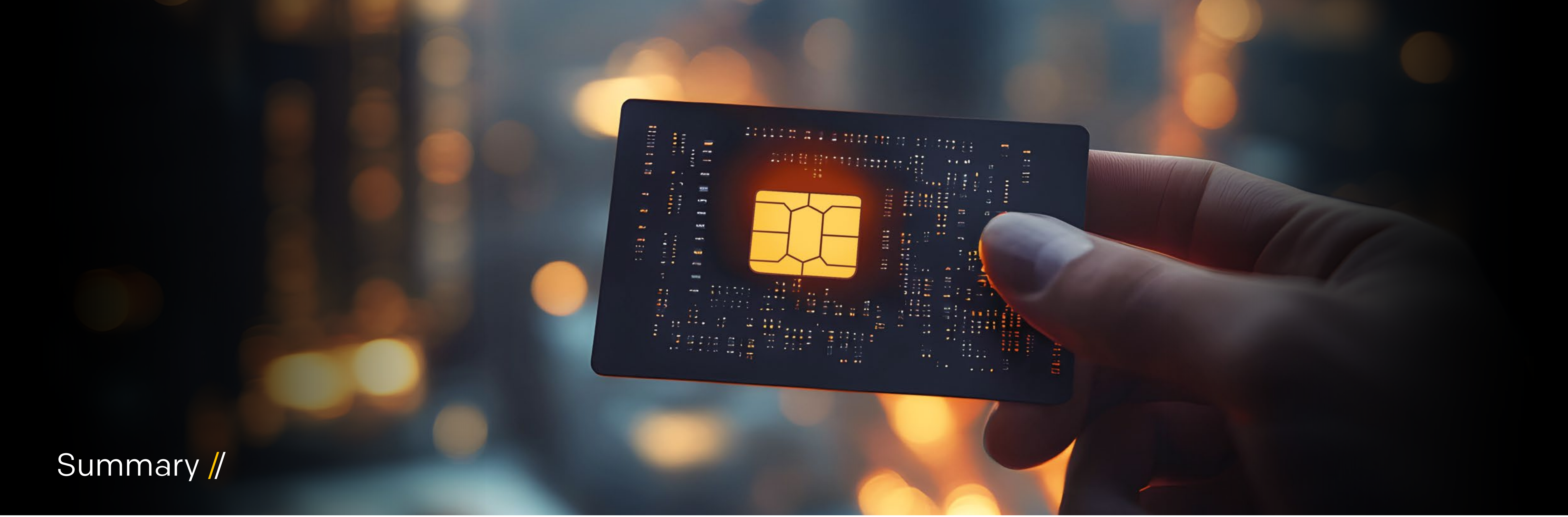
Lab-on-a-chip is a buzzword that would not work without active microfluidics. Integrated point-of-care diagnostic applications are the goal of this technology. Time-consuming and costly laboratory diagnostics can thus be reduced to a minimum. With surface acoustic waves (SAW), liquid samples are manipulated, separated and transported on inexpensive microchips. The structure sizes are in the meso range. A notable example is the characterization of phononic cones at 9.35 MHz with 190,000 scan points and amplitudes below 1 nm for the development of integrated diagnostic systems.



13 Surface waves for droplet manipulation

MIDDLE EAR MECHANICS

In otology meso-structures are the norm, but they are also embedded in a macro-structure, the skull. With the attachment optics, the complex vibration modes of eardrums can already be measured in vivo. The ossicles are accessible for single-point vibrometers during microsurgical operations, where they are used for quality control of implanted hearing aids. For area measurements they are only accessible as specimens. The focus here is on analyzing the transfer function of the ossicular chain and its coupling to the inner ear.



Summary //

The characterization of vibrations and movements requires special optics for structures of different dimensions. The field of view and depth of field must be balanced in order to optimally fulfill the respective task.

Special microscopic instruments (MSA) resolve an order of magnitude more structural details, but limit the field of view. VibroScan QTec addons extend the range of applications to meso- and even microstructures, while specific software features enable precise target alignment and high resolution for meso components.

The systematic application of non-contact laser vibrometry in the development of consumer electronics, especially smartphones, demonstrates the broad spectrum of the technology from overall system analysis to the characterization of individual MEMS components.

This application note is based on the practical experience of the Application Engineering Team and documents proven measurement techniques for the characterization of meso-structures.