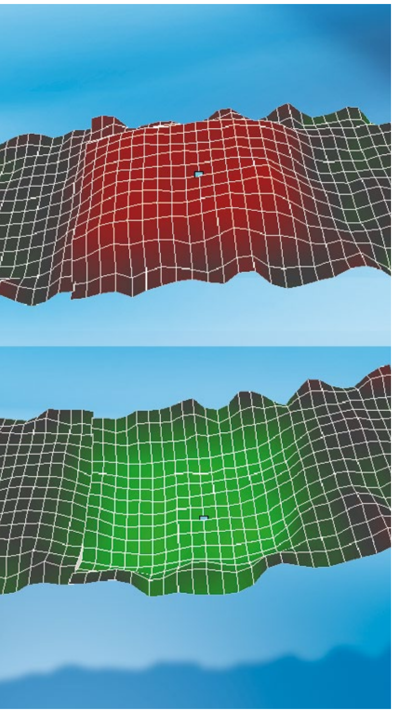


Ultra High Frequency and Full-Field Vibration Analysis

Performance Testing of Microsystems

Application Note

Measuring Surface Vibrations on Ultrasound Transducers with the UHF-120 Ultra High Frequency Vibrometer.

An increasing number of micro-manufactured sensors, actuators and components vibrate today at frequencies in the high MHz range. A few examples of such high-frequency vibrating systems are: MEMS (Micro-ElectroMechanical Systems, NEMS (Nano-ElectroMechanical Systems) as well as Surface Acoustic Wave (SAW) filters and ultrasound sensors, as used for example for imaging in medical applications. To test the functionality of these components, to check existing simulation models and to optimize the design of the systems, you have to measure their dynamic behavior. One of the few available solutions for vibration measurement in such systems is to use a laser vibrometer to make measurements without contact and which are virtually non-invasive.

Until recently, Polytec vibrometers reached a maximum measurement frequency of 24 MHz. With the new UHF-120 Ultra High Frequency Vibrometer, it is now possible to easily and reliably determine the vibration characteristics of high-frequency vibrating systems (Fig. 1) up to a frequency of 1200 MHz.

1
Typical frequency range of high-frequency components

Application	Frequency range
RF-MEMS	1 MHz - >3 GHz
SAW Filter	10 MHz - >60 GHz
NEMS	50 MHz - >1 GHz
HF Ultrasound Transducer	1 MHz - >1 GHz

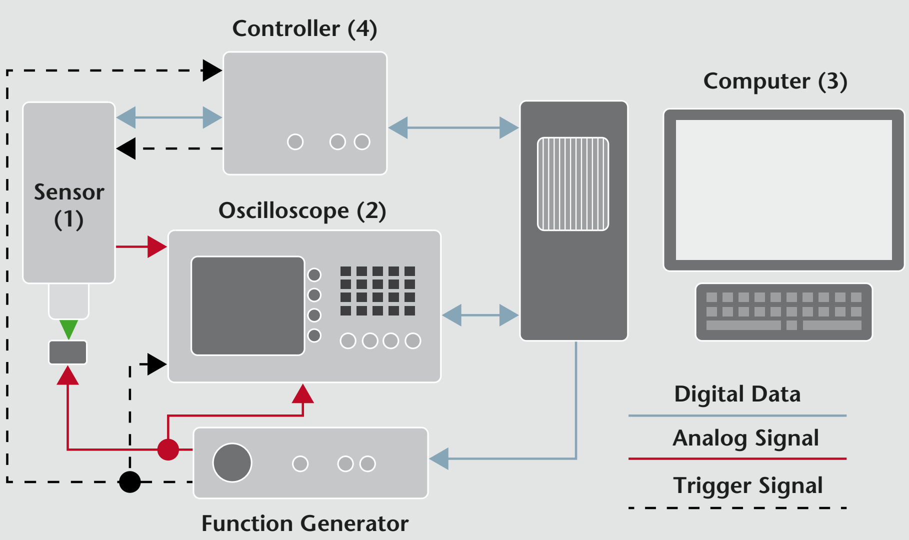
In Measurement Principle and Design of the UHF-120 Ultra High Frequency Vibrometer

The operating principle of the UHF-120 is based on laser Doppler interferometry, the same as all other Polytec vibrometers. When the laser beam from the vibrometer hits a moving object, the frequency and phase of the light scattered back is shifted by the Doppler effect. T his frequency and phase shift is determined interferometrically.

The UHF-120 sensor head based in the microscope (Fig. 2, 3) contains a heterodyne Mach Zehnder Interferometer. Interference of the Doppler shifted object beam with a reference beam results in a beat signal. Beating is the interference of two coherent waves with a similar frequency. If the object not only moves in a line, but oscillate backwards and forwards, a frequency and phase modulated signal is generated which contains all the information on the vibration of the object. This signal is sampled using a commercial oscilloscope with a sample rate of up to 40 GigaSamples/second and is digitized. The digitized data is then transferred to the PC via Ethernet and there it is demodulated and analyzed using the Polytec software.

The total UHF-120 system (Fig. 3) includes the sensor head (1), the measurement computer (3), the oscilloscope (2) and also a controller (4) as the interface between the measurement computer and the sensor head. In the event that the UHF-120 is to be used to make a scanned (surface) measurement, the total system is simply expanded by a motorized X/Y positioning stage.

2
UHF-120 with sensor head (1) and controller (4).



3
Information flow in total UHF-120 system

Measuring Ultrasound Sensors

Both designs of ultrasound sensors to be measured were developed by the Fraunhofer Institute for Biomedical Engineering (IBMT, St. Ingbert) and are used in medicine for abdominal imaging, cellular imaging and measuring surfaces. The aim is to determine the three-dimensional sound field dispersion in space by measuring the out-of-plane vibration of the components.

Operating Principle of Ultrasound Sensors

Both kinds of ultrasound sensors work both as transmitter and receiver of ultrasonic waves (ultrasound transducer). Depending on the function and mode of operation of the two arrays, there is either a thin membrane (100 MHz Array) or an impedance-matching layer (5 MHz) above a Piezo array. By applying a voltage to a defined field of the Piezo array, both the amplitude and the phase of deflection of each Piezo field can be varied. The crystal vibration (out-of-plane) caused by the Piezo effect is transmitted to the thin membrane or matching layer above it.
The membrane or adapter layer excited to vibrate then generates an ultrasound wave, the shape and frequency of which can be changed by varying the control of the Piezo field. By selecting the correct amplitude and phase for each array element, it is possible, for example, to generate a focused ultrasonic wave with a variable point of focus with the low-frequency sensor.

Measurement Using Sensor 1 („Low-frequency ultrasound sensor")

This sensor is used for abdominal imaging. The component has a surface of approx. 10 x 10 mm^2 and has a vibration frequency of 5 MHz. A 5x objective was used when making a measurement on the low-frequency sensor. The field of view captured by the camera with a 5x objective is 1.42 x 1.1 mm^2. To characterize the sensor across the whole surface of approx. 10 x 10 mm^2, a total of 30 individual fields (5 x 6) were scanned and measured one after the other. In each individual area of interest (AOI), 234 measurement points were defined. During the scan, the amplitude and phase were recorded at every scan point over a time span of 20 µs. The start of every individual measurements was initiated by a trigger signal. This trigger signal is simultaneously used as the phase reference.

The data from the individual scanned fields recorded in this way were then joined together using the Polytec software and were animated. In the following 8 pictures (Fig. 4 to 11) you can see an excerpt of the animation of the vibration progress. The total vibration time is approx. 5 µs and has a maximum amplitude of ±40 nm (peak to peak). Figure 12 shows the amplitude time profile of a selected measurement point.

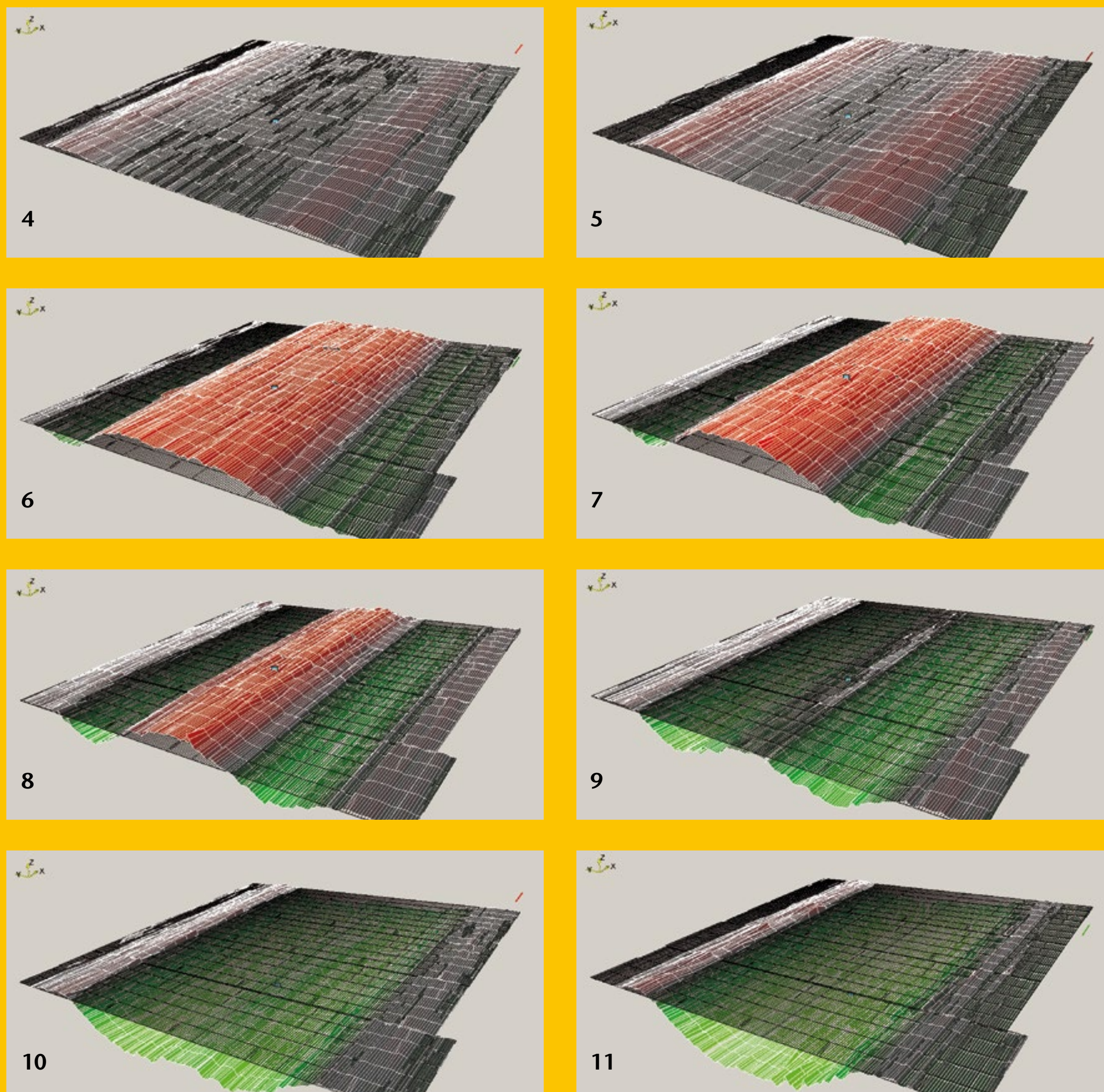
From the pictures it can be seen that it is possible to generate ultrasonic waves in certain shapes with regulated excitation of a Piezo array and a thin impedance-matching layer above it .

If you look at the profile of the vibration in the first 4 individual images, you recognize that first of all the edge areas and after that the middle areas of the membrane are excited to vibrate. Therefore the outer part of the ultrasonic wave starts earlier than the middle. As a result, you get the desired type of spherical wave which after a certain distance runs into a focal point.

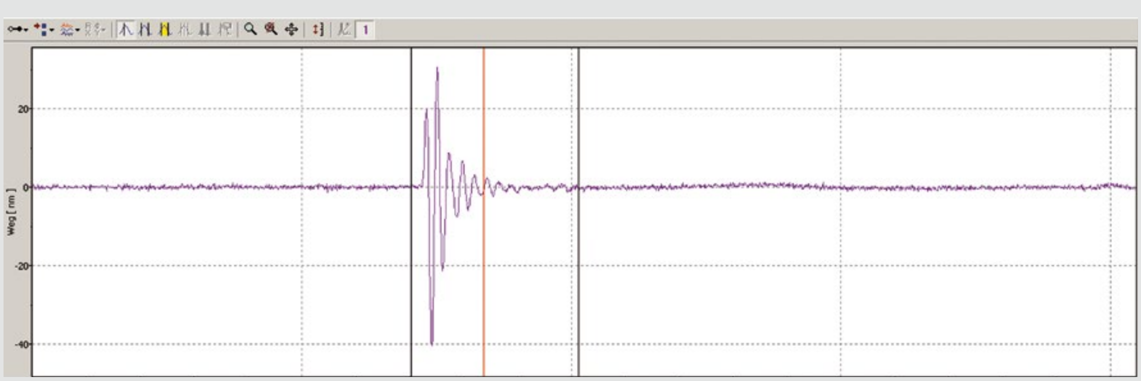
Analysis of the Data by the IBMT

The first animations of the measurement data with the Polytec software already allowed the development team at IBMT to ascertain that the principle vibration behavior of the membrane matched the existing simulations. A detailed analysis of the measurement data also allowed the existing vibration model to be improved and corrected. When analyzing the data, it had to be taken into consideration that during the measurement, the membrane was not operated in water as it would be in real life, but in air without the damping normally produced by the water. With the new revised simulation model it is now possible for the IBMT to simulate the vibration of the membrane and thus also the three dimensional propagation of the resulting ultrasonic wave. As an alternative to the conventional measurement of the three-dimensional noise field, it is now possible to evaluate the function of the component in a significantly shorter time.

4-11
Vibration characteristics of the low-frequency ultrasonic sensor



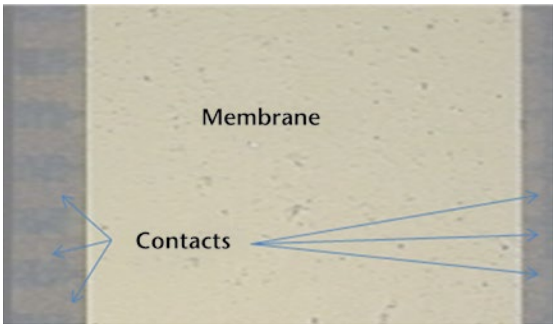
12
Amplitude time profile of a selected measurement point



With the UHF-120 Vibrometer, it is Relatively Easy to Determine the Vibration Characteristics of High-Frequency Vibrating Systems with Great Precision.

Measurement Using Sensor 2 („High-frequency ultrasound sensor“)

This type of sensor is used for cellular imaging and making surface measurements. It has a surface of approx. 0.8 x 2.4 mm^2 and has a vibration frequency of 105 MHz. When measuring the high-frequency ultrasound sensor, a total of 3 individual areas also had to be scanned and measured one after the other using the 10x objective. Each AOI was given 405 sample points. Other than with the measurement of the low-frequency sensor, this one was covered with a 1 mm thick layer of water on top of which there was also a thin piece of cover glass. This allowed a realistic measurement of the transducer to be made. In contrast to the low-frequency sensor, in which a focused ultrasonic wave is generated by the vibration of the membrane, the high-frequency sensor can only cause simultaneous excitation of the elements and thus a sort of scan be conducted. Depending on which contacts (Fig. 13) are controlled on the sensor, different areas of the membrane are excited to vibrate. Thus for example, with a „scanning ultrasonic measurement“, various areas of the membrane can be made to vibrate in phase with each other, thereby transmitting level sound waves at various positions. The sound waves generated like this are reflected in the object under test and are then detected again by the ultrasound sensor.



13
Microscope shot of the high-frequency ultrasonic sensor with a 1 mm thick layer of water and a cover glass

The following 9 pictures (Figures 14 - 22) show the results after excitation of four Piezo fields in the middle area of the ultrasound transducer. It can be seen that a surface vibration of the membrane is generated by the Piezo array over a sharply defined area. The settling process of the membrane vibrating at around 105 MHz is approx. 0.5 µs. The maximum amplitude of the membrane corresponds to a bit more than 150 pm, as can be seen in Figure 14. Based on the deflection shape of the membrane, it can clearly be seen that as a result of the strong attenuation by the layer of water, only the area of the membrane excited by the Piezos immediately beneath it will start vibrating. It can also be seen that an almost flat and simultaneously spatially sharply focused sound wave is generated by the membrane.

[1] When analyzing the results of the high-frequency sensor, it was necessary to ensure that the sensor in the reference system moved in water. The optical path, i.e. the path that the light takes, is calculated from the geometric path multiplied by the r efractive index. Water with a refractive index of n = 1.33 has a larger refractive index than air (n = 1). Therefore the optical path of the light in water in a factor of 1.33 greater. Thus the vibrometer measures a path that is a factor of 1.33 too big. To obtain the correct amplitude value, you have to divide all the measurement results by 1.33 which, however, can be done without any great effort by the PSV software with the aid of the signal processor.

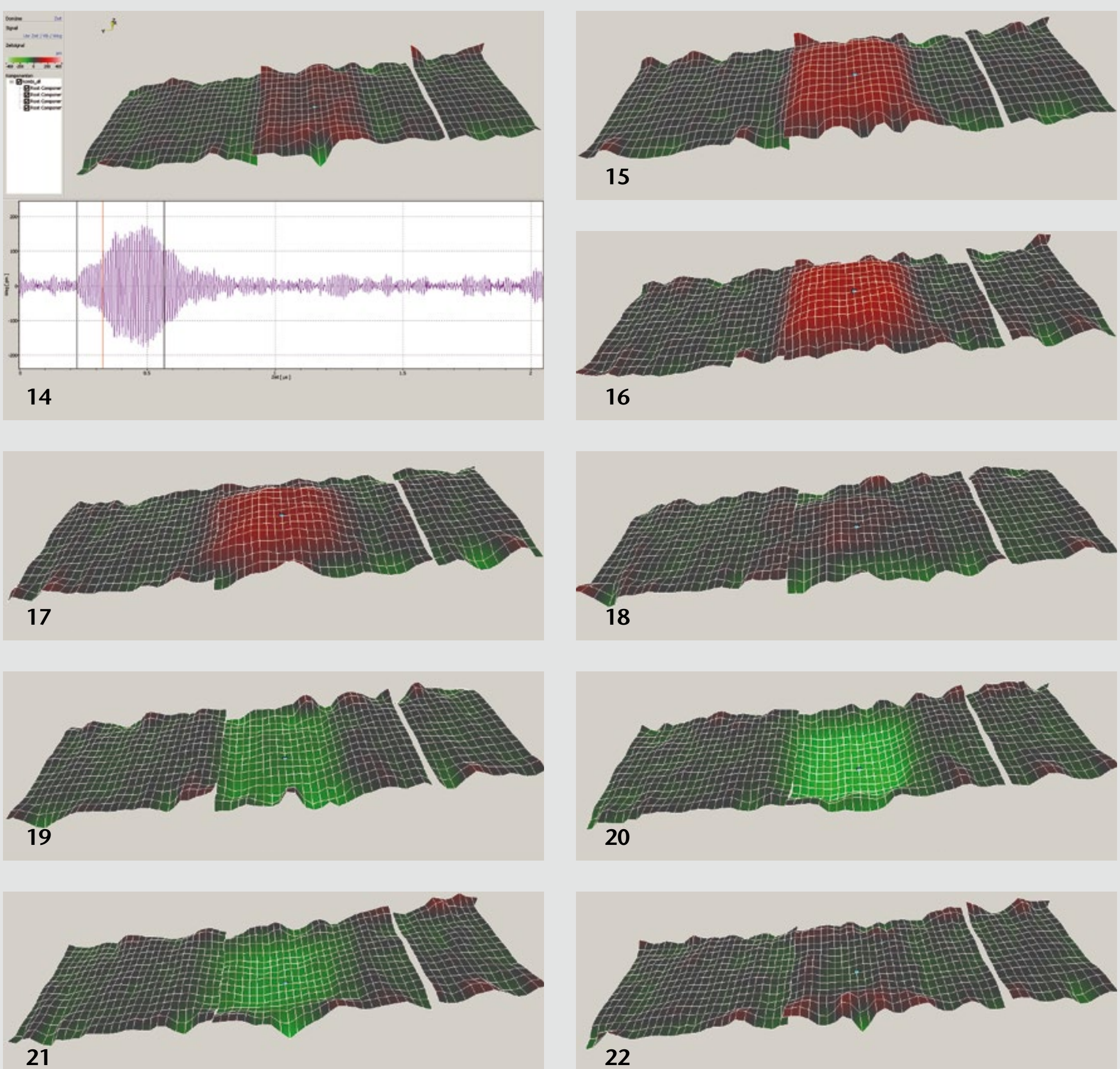
Analysis of the Data by the IBMT

On the basis of the out-of-plane vibration measured in the water[1], it was again possible for the IBMT to spatially simulate the sound field generated using a model. The measurement in the water thus serves as a realistic basis for the simulated sound field.

Summary

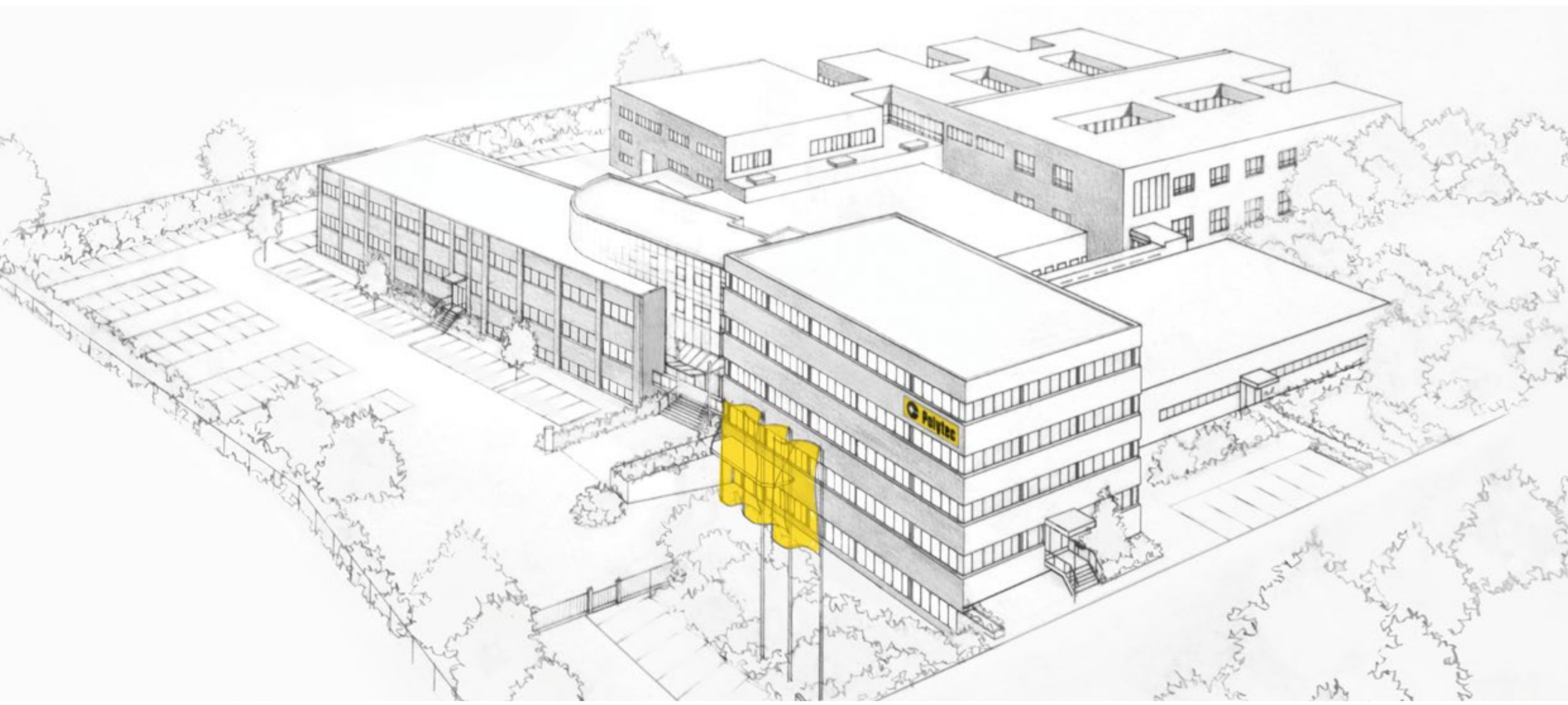
With the UHF-120 Vibrometer, it is relatively easy to determine the vibration characteristics of high-frequency vibrating systems with great precision. Apart from the high accuracy of the measurement procedure, the small amount of time required is a significant advantage of the UHF-120 that can be decisive in the development process in particular.

At the IBMT, it has been possible to significantly reduce the time required to determine the ultrasonic field through surface measurement of the transducer. As an alternative to measuring the three-dimensional sound field using a noise sensor installed in the room, it is now possible to determine the resulting sound field simply with one or more scanned measurements and the subsequent simulation.



14 - 22
Vibration characteristics of the high-frequency ultrasound sensor.

Polytec



Polytec GmbH (Germany)
Polytec-Platz 1-7
76337 Waldbronn
Tel. +49 7243 604-0
info@polytec.de

Polytec GmbH (Germany)
Vertriebs- und Beratungsbüro
Schwarzschildstraße 1
12489 Berlin
Tel. +49 30 6392-5140

Polytec, Inc. (USA)
North American Headquarters
16400 Bake Parkway
Suites 150 & 200
Irvine, CA 92618
Tel. +1 949 943-3033
info@polytec.com

Central Office
1046 Baker Road
Dexter, MI 48130
Tel. +1 734 253-9428

East Coast Office
1 Cabot Road
Suites 101 & 102
Hudson, MA 01749
Tel. +1 508 417-1040

Polytec Ltd. (Great Britain)
Lambda House
Batford Mill
Harpenden, Herts AL5 5BZ
Tel. +44 1582 711670
info@polytec-ltd.co.uk

Polytec France S.A.S.
Technosud II
Bâtiment A
99, Rue Pierre Semard
92320 Châtillon
Tel. +33 1 496569-00
info@polytec.fr

Polytec Japan
Arena Tower, 13th floor
3-1-9, Shinyokohama
Kohoku-ku, Yokohama-shi
Kanagawa 222-0033
Tel. +81 45 478-6980
info@polytec.co.jp

Polytec South-East Asia Pte Ltd
Blk 4010 Ang Mo Kio Ave 10
#06-06 TechPlace 1
Singapore 569626
Tel. +65 64510886
info@polytec-sea.com

Polytec China Ltd.
Room 1026, Hanwei Plaza
No. 7 Guanghua Road
Chaoyang District
100004 Beijing
Tel. +86 10 65682591
info-cn@polytec.com

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