1D, 2D MEMS microscanners – vector scanner (quasi-static) or resonant scanner with integrated position sensors

Fraunhofer IPMS has many years of experience in the customized development of MEMS microscanners. These consist of an optically active surface – a mirror or a diffraction grating – which can be tilted or moved translationally around one or two axes of rotation. Both a 2D vector and a 2D resonant scanner or a combination of the two types is possible.

With quasi-static MEMS scanner mirrors, the tilting movement can be modulated from a static deflection to an angle to freely defined angular changes (with an upper frequency and amplitude limit). Resonant scanner mirrors are operated close to their resonant frequency defined by the design in order to achieve the maximum deflection for the selected drive voltage.

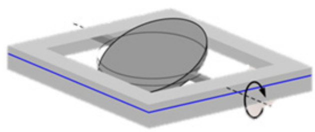
The range of available scanner mirrors is characterized by a large optical scanning range, a wide range of realizable frequencies, different mirror geometries and various mirror surface designs. The microscanners are extremely reliable in operation. They are equipped with a monolithically integrated position sensor system for precise control and regulation of their mechanical movement. The reflective surface of the MEMS scanners has a reflectivity of approx. 90 % in the visible range. It is also possible to apply a customized, highly reflective dielectric mirror coating.

The 1D and 2D MEMS microscanners are manufactured in volume micromechanics from monocrystalline silicon in a qualified, CMOS-compatible MEMS process suitable for series production. The technology of these scanner mirrors is continuously being expanded in its range of applications through innovative and patented design solutions as well as application-specific technology modules. Fraunhofer IPMS has already developed more than 200 different microscanner designs and manufactured them in its own clean room.

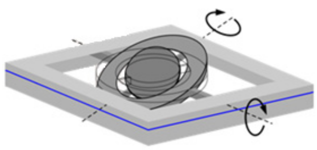
Our portfolio in the field of MEMS scanner mirrors is rounded off by evaluation kits, customer support in the development of specific module designs, and electronics solutions for controlled actuation that exploits the precision of the scanners.

Selection of MEMS microscanner designs

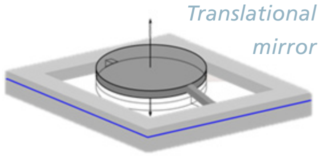
1D tilting mirror



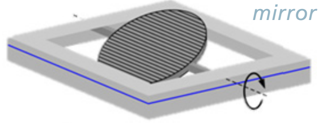
2D tilting mirror



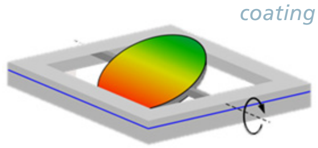
Translational mirror



Grating mirror



Highly reflective coating



Design spaces and parameter examples of 1D and gimbal 2D MEMS microscanners

Gimbal MEMS scanners and parameter examples

Type	Mode	Parameter ranges of different designs			Parameters of selected sample designs		
		Mirror size (1)	Amplitude (2)	Frequency (3)	Mirror size (1)	Amplitude (2)	Frequency (3)
Tilting mirror 1D	quasi-static	1 … 6 x 8 mm²	up to 10.5°	up to 2.4 kHz	2 x 3 mm²	9.5°	550 Hz
	resonant	0.5 … 7 mm²	up to 25°	up to 100 kHz	3 x 3 mm²	9.5°	6.0 kHz
Tilting mirror 2D	quasi-static | resonant	up to 5 x 7 mm²	up to 10° | up to 22°	up to 1.2 kHz | 37 kHz	2.5 x 1.8 mm²	10° | 17°	180 Hz | 4.5 kHz
	resonant | resonant	up to 3 x 4 mm²	up to 28° | up to 21°	up to 25 kHz | up to 42 kHz	3.3 x 3.5 mm²	11° | 8°	150 Hz | 110 Hz
Translational	resonant	up to D = 5 mm	up to 500 µm	12 kHz	2.0 x 2.0 mm²	500 µm	12 kHz

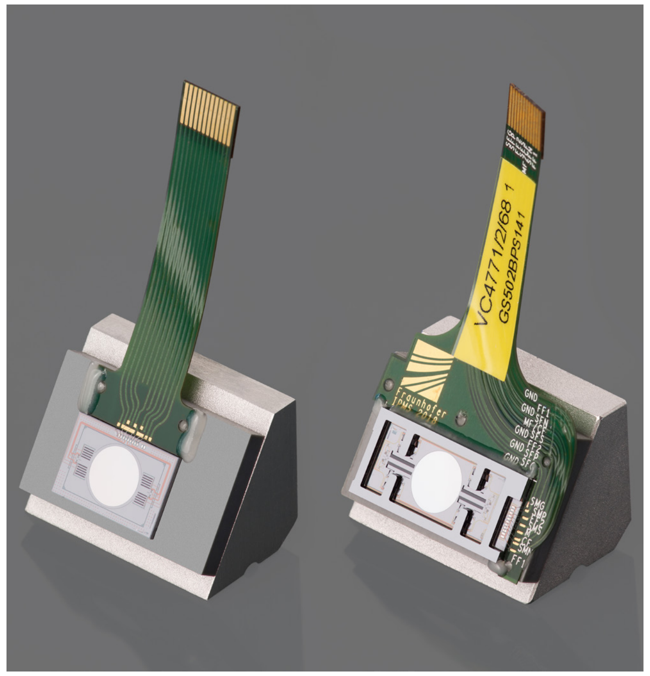
1) Typical mirror geometry: round/elliptical, rectangular for selected designs
2) Amplitude: **Mechanical scan amplitude** (mechanical scan range = 2x amplitude, optical field of view = 4x amplitude due to reflection)
3) Frequency: **Resonance frequency** (the maximum frequency of linearized trajectories in quasi-static scanners is about one fifth of this value)

1D design spaces for resonant and quasi-static mirrors

The parameters mirror diameter, natural frequency and deflection are important and mutually limiting variables. In addition, other parameters such as optical planarity, shock and vibration resistance as well as the lowest possible drive voltages and chip dimensions must be achieved during the design and layout process.

The table above with the microscanner design examples and the listing of resonant and quasi-static design spaces provides an initial orientation with regard to the feasibility of design ideas. Special cases outside these outlined design spaces are also possible. These are typically evaluated as part of feasibility studies. For the resonant design space, the design freedoms increase significantly for natural frequencies <2 kHz. In addition, a quasi-static frame axis can be combined with a resonant mirror axis as a gimbal 2D MEMS scanner. For electrostatic 2D MEMS scanners with two quasi-static axes, the information under 2D vector scanners on page 6 applies.

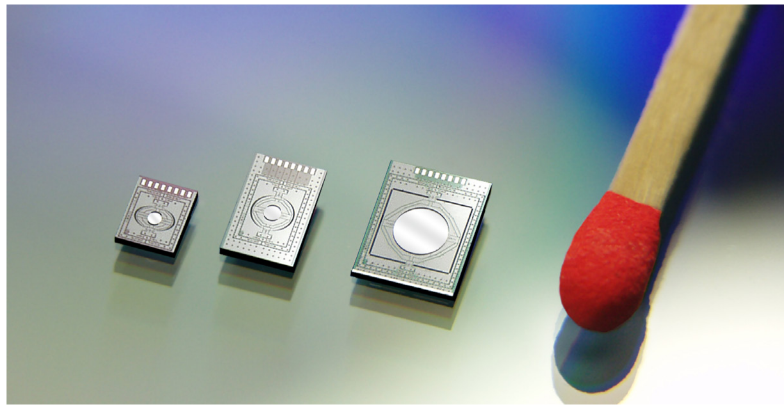
Get in touch with us to discuss your specific application.



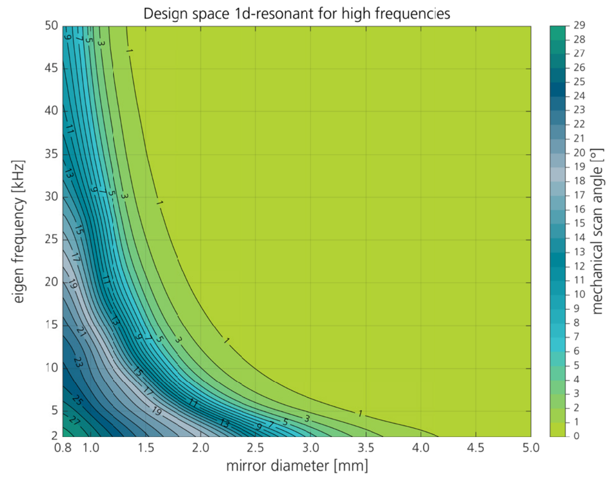
1D MEMS scanner, identical aperture 5 mm
left: 1D resonant, right: 1D quasi-static

Design spaces for 1D resonant MEMS scanners

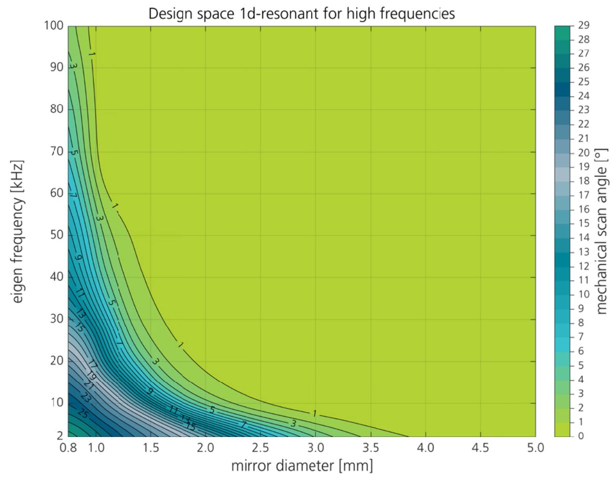
At higher natural frequencies, attention must be paid to the dynamic deformation of the mirror plate, depending on the application and wavelength used. This means that the deformation of the mirror plate must be sufficiently small so as not to negatively affect the beam quality of the reflected light. A maximum value of 100 nm has been assumed for this deformation so that the design spaces for the resonant MEMS scanners can be represented. For a specific customer design, we take into account the tolerable value for the respective application in the design simulations.



Resonant MEMS scanners with small mirror aperture



1D resonant for frequencies up to 50kHz

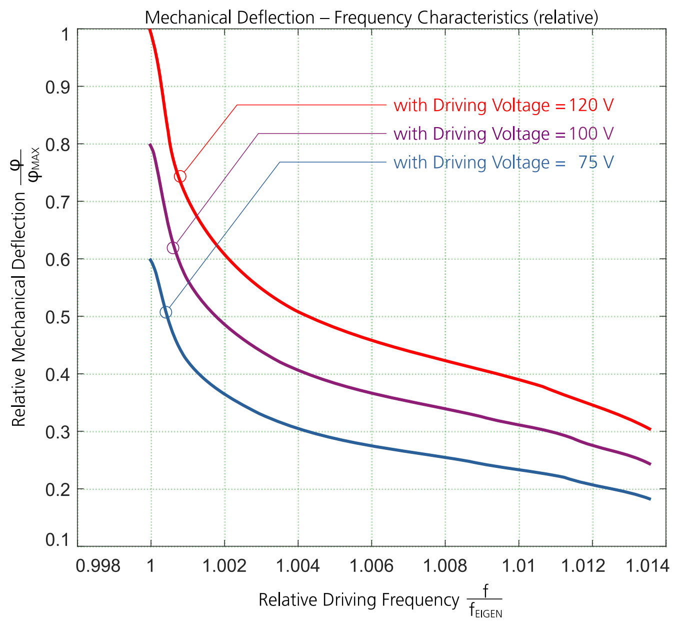


1D resonant for frequencies up to 100kHz

Specifics of resonant microscanner mirrors

The mirror plate of the microscanner demonstrators is excited to resonant oscillation by electrostatic, planar comb drives. The oscillation amplitude is set by adjusting the drive voltage or the excitation frequency. In 2D microscanners, the mirror is suspended on a gimbal. The frequency of the two oscillations is set independently of each other in the design. Each of the two axes is excited individually so that the amplitude of each oscillation can be set and controlled independently of the other.

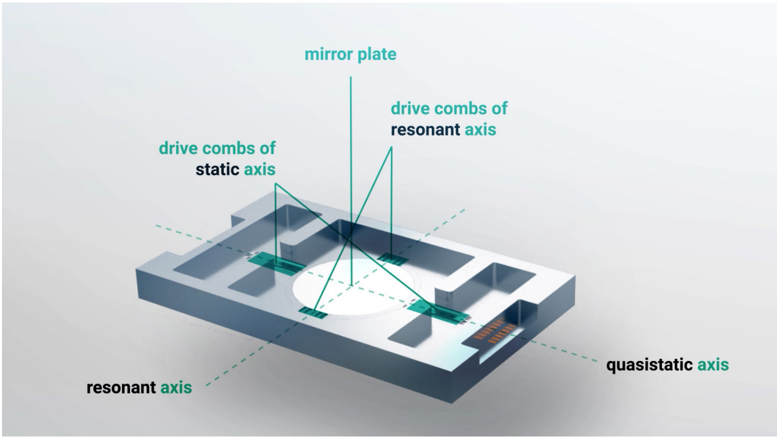
Resonant scanner mirrors are operated with a square wave voltage, which can be provided by a commercially available function generator, if necessary with an amplifier. Alternatively, we can offer you the appropriate electronics – including trigger generation and amplitude control.



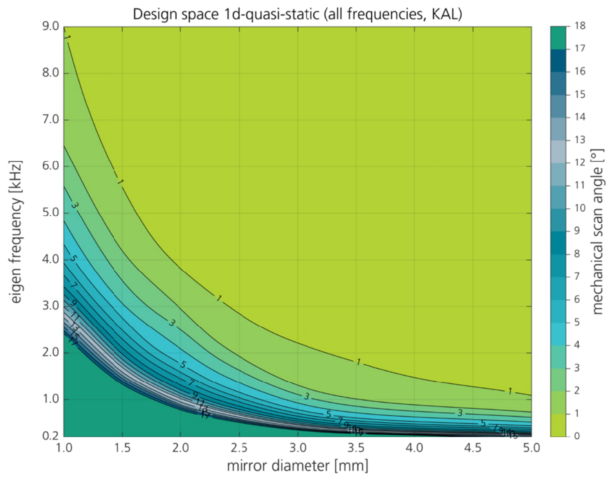
Typical frequency-deflection characteristics of resonant scanner mirrors

Design spaces for 1D quasi-static MEMS scanners

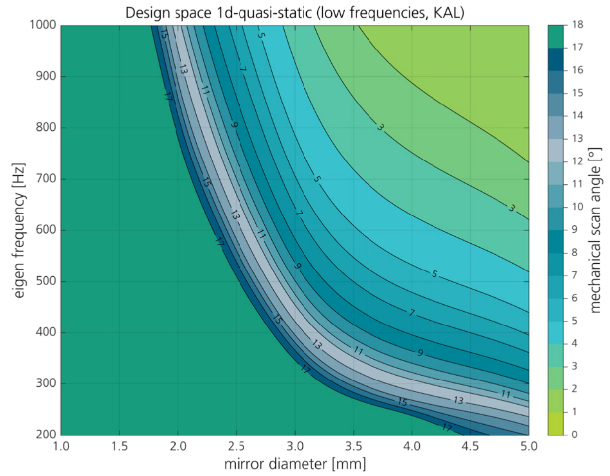
The natural frequency is also a very important parameter for quasi-static MEMS scanners. In contrast to resonant oscillating scanners, which are operated close to their natural frequency, quasi-static scanning should be significantly below the natural frequency in order to keep the settling times for the addressed target positions low and to be able to control or regulate any given scan trajectories with high accuracy.



Setup of a Linscan microscanner with second resonant axis



1D quasi-static for natural frequencies up to 9 kHz

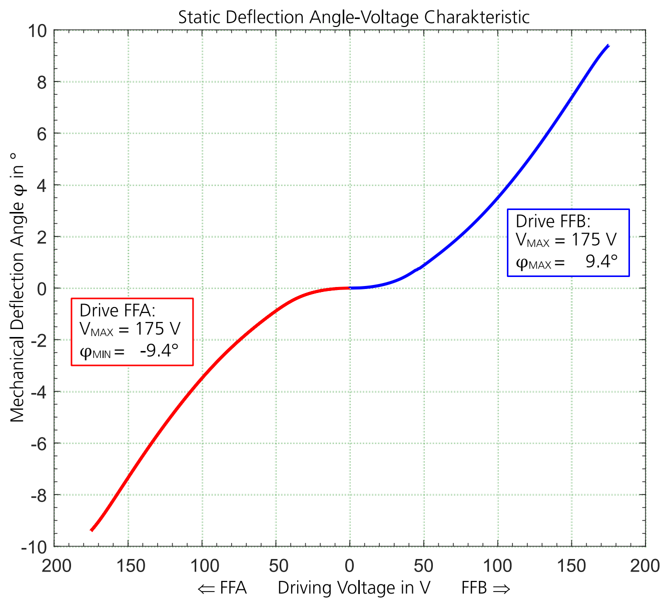


1D quasi-static for natural frequencies up to 1 kHz

Specifics of quasi-static »LinScan« microscanners

LinScan microscanners are equipped with an electrostatically quasi-statically operated drive axis, which is realized via vertical comb drives. Depending on the application and specifications, angled (AVC or CAVC) or layered (SVC) vertical comb drives are used. In 2D microscanners, the inner gimbal mirror axis is realized via a resonant drive. Planar comb drives are used for this purpose.

All mechanical components are created as two-dimensional structures in a layer of monocrystalline silicon. In an adhesive wafer bonding process with a second, planar structured silicon wafer, the vertical comb electrodes are created by pre-deflection from the substrate and subsequent fixation by the wafer bond. The vertical displacement of the electrodes is carried out by mechanical solid-state mechanisms. This achieves a mechanical decoupling in the realm of manufacturing tolerances, resulting in a very precise alignment of the electrodes to each other.

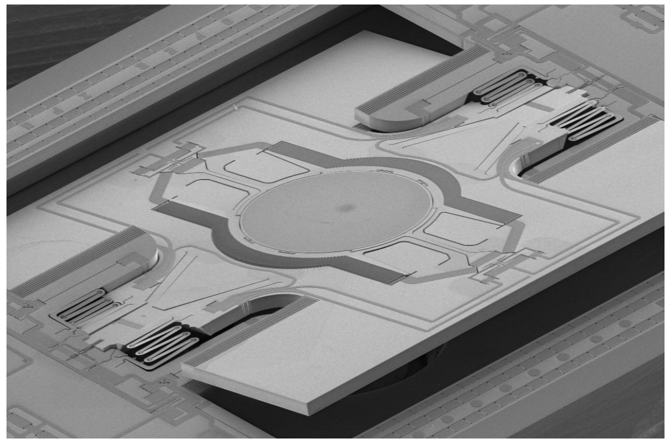


Typical static voltage deflection characteristic of a quasi-static scanner

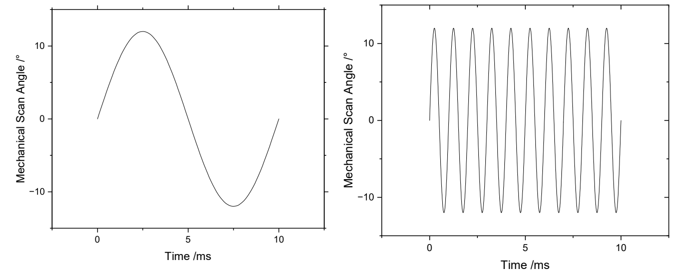
Gimbal 2D MEMS scanners

The 1D MEMS scanners described can be combined on the chip with gimbal suspension, i.e. mechanically decoupled axes, to create 2D scanners. Two options are available: Firstly, the combination of a quasi-static frame axis with a resonant inner mirror axis or two resonant oscillating mirror axes.

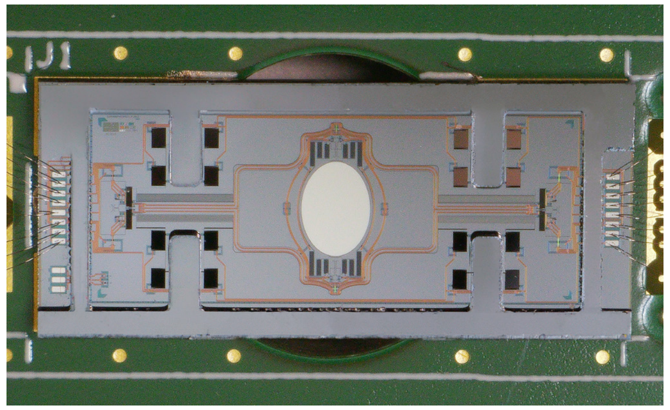
The effect on the 2D scan trajectory for the combination options is shown as an example in the following images. In double-resonant scanners, a slow resonant axis is combined with a fast resonant axis. A slow quasi-static axis in combination with a fast resonant axis results in a quasi-static resonant scanner.



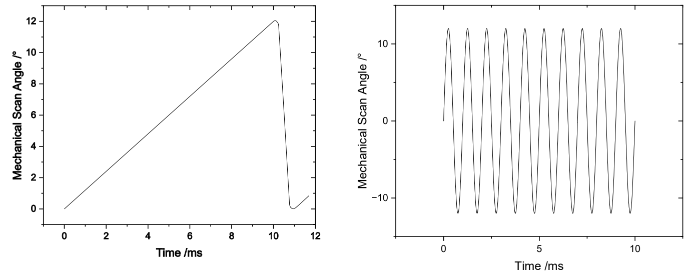
MEMS scanner 2D resonant: frame frequency 100 Hz, mirror frequency 27,600 Hz



Double resonant scanner (left) with trajectories of a slow resonant axis (center) and a fast resonant axis (right).



MEMS scanner 2D quasi-static / resonant: frame frequency 170 Hz, mirror frequency 4,500 Hz

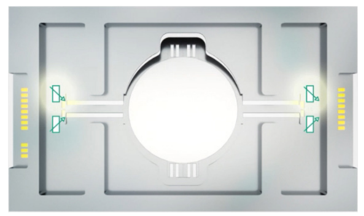


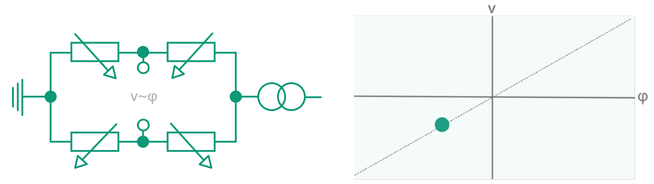
Quasi-static resonant microscanner (left) with trajectories of a slow quasi-static axis (center) and a fast resonant axis (right).

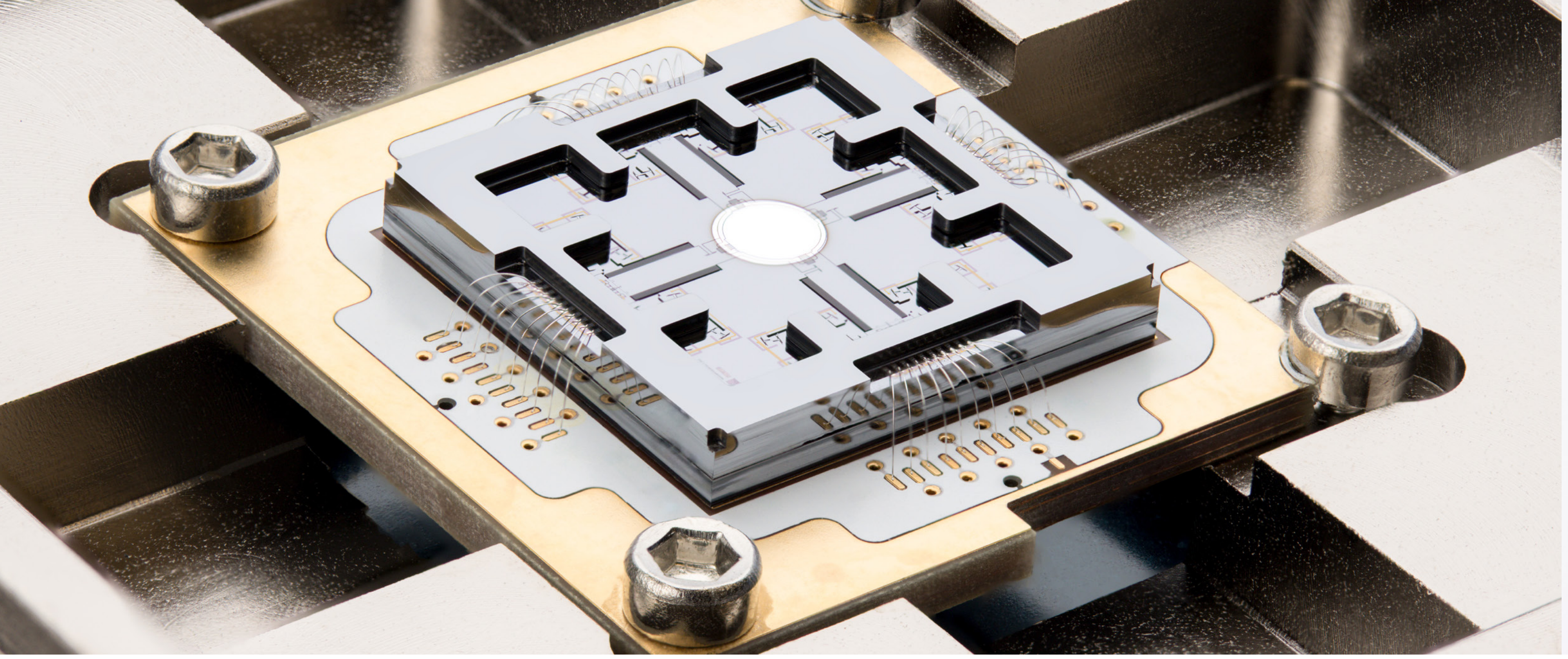
Monolithically integrated piezoresistive position sensing

All 1D and 2D MEMS scanners have monolithically integrated piezoresistive position sensing for each torsional axis embedded in the chip. These are linearized via the connection of a Wheatstone measuring bridge and the sensitivity is increased so that the mechanical deflections of the mirror and frame axis can be measured continuously.

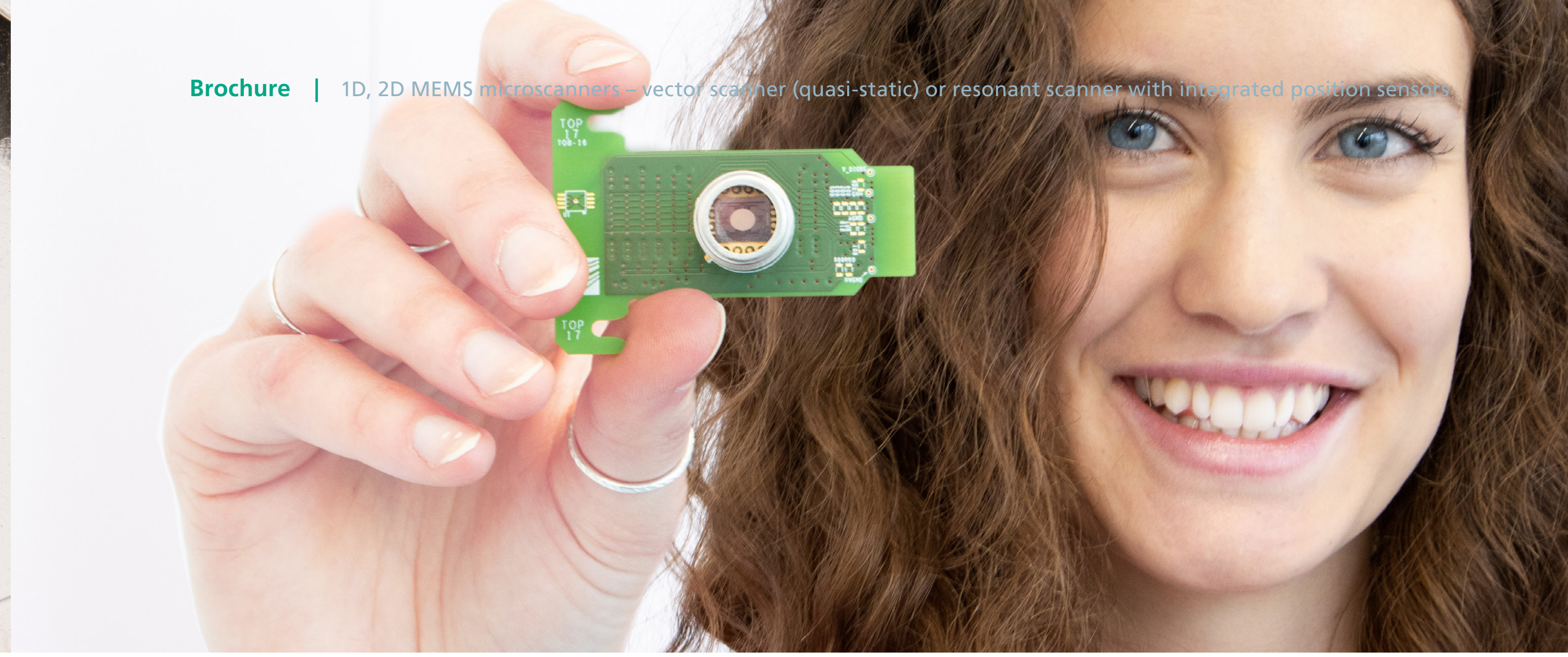
Monolithic integrated position sensing





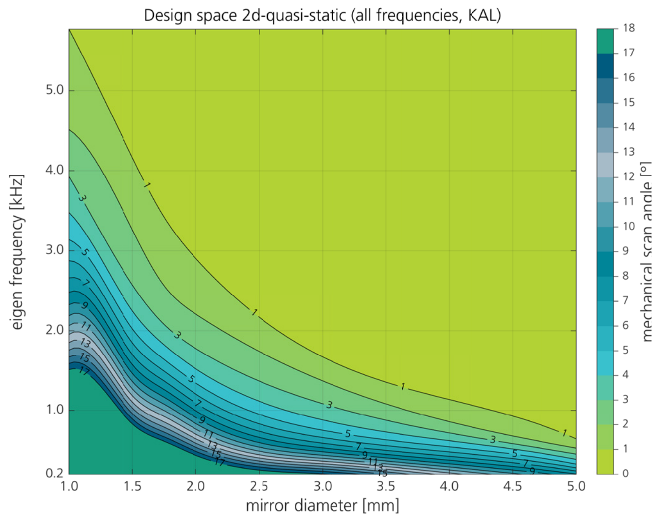


Multilase device

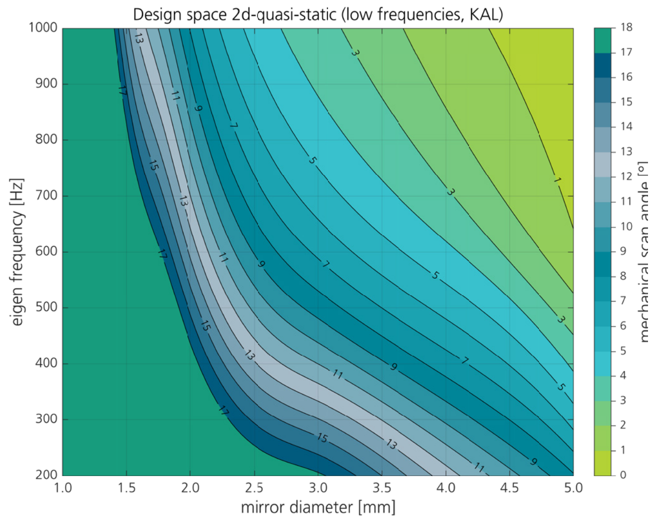


2D vector scanners (non-gimballed)

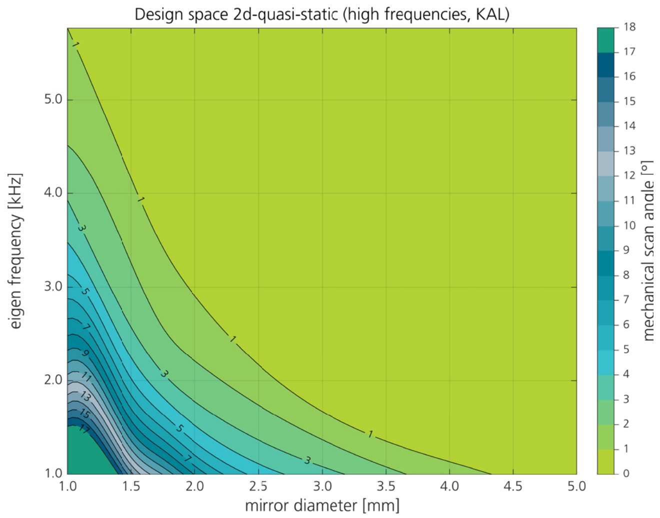
New in the family of IPMS technology AME75 based MEMS microscanners are non-gimballed vectorial 2D scanners with integrated position sensors. The lower design spaces have been created on the basis of two design points that have already been realized. These specify the ranges for deflection, natural frequency and mirror diameter in which customized scanner designs can be definitively created and manufactured on the basis of reasonably assumed parameter restrictions. In addition, other parameter combinations that cannot be found here are also possible, but whether a design can be created must then be assessed as part of a feasibility study.



Design space with constant drive capacity



Design space for natural frequencies up to 1 kHz



Design space for natural frequencies from 1 kHz – 5 kHz

Evaluation kits (gimbal scanners)

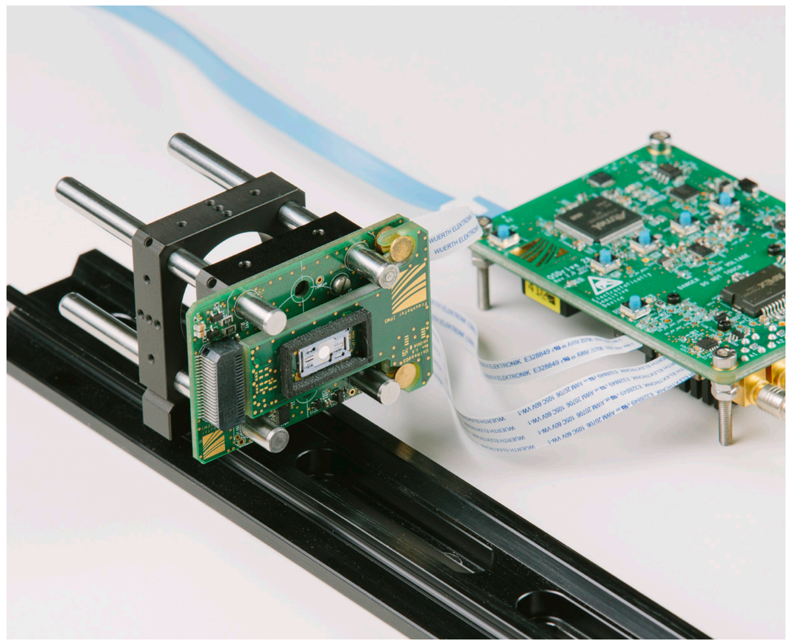
Fraunhofer IPMS offers various evaluation kits that enable small and medium-sized companies in particular to operate MEMS scanner devices from Fraunhofer IPMS in accordance with specifications without having to develop their own control electronics. All that is additionally required is a power supply and a computer on which our control software can run. control electronics that enable the devices to be operated with an optimized trajectory. The device is held by a scan head, which is also included in the scope of delivery and can be easily integrated into standard optical test setups thanks to its special design. Depending on the design of the MEMS device, controlled operation of the device and synchronized operation of the resonant axis are also possible. The function is controlled by software that communicates with the electronics via USB.

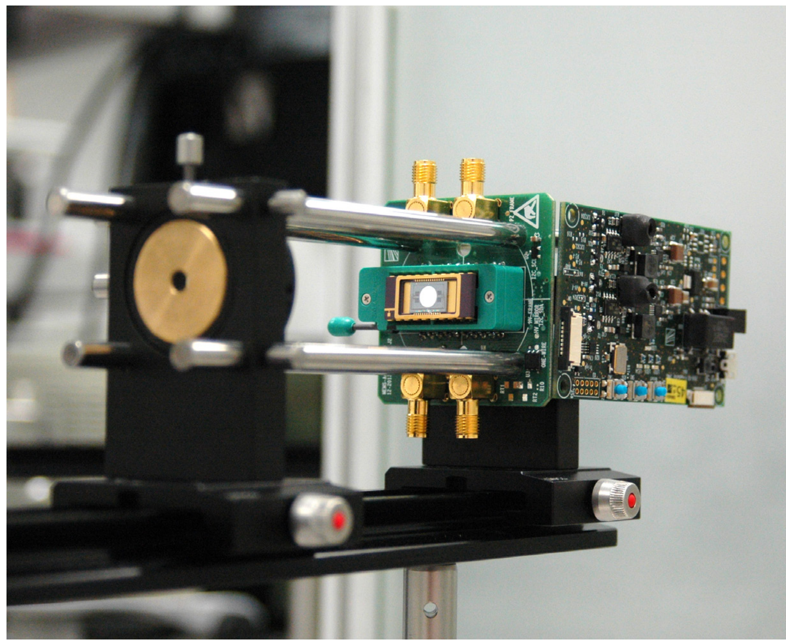
QSDrive scan kit for quasi-static MEMS

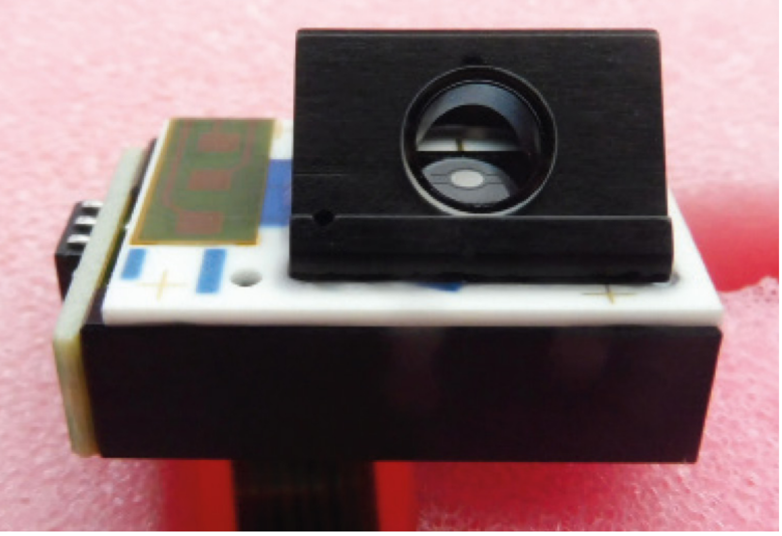
The »QSDrive Scan Kit« evaluation kit consists of a Reso-Lin device – a gimbal MEMS scanner with a linear axis and an optional orthogonally oriented resonant axis – as well as

SiMeDri for resonant MEMS scanners

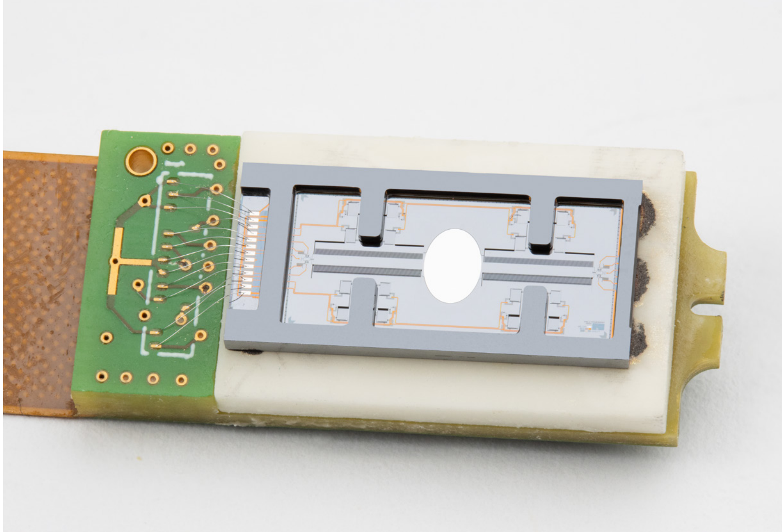
The SiMeDri evaluation kit is an electronic drive unit for the control of resonant 1D and 2D microscanner mirrors. It consists of a driver board and a MEMS board that can be plugged together directly.







▲ *Scan module with 1D resonant Fraunhofer IPMS scanner, used in the light sheet microscope ZEISS Lightsheet 7*



▲ *Quasi-static scanner in a module for head-mounted displays*

Applications of MEMS microscanners

- Image acquisition e.g. for technical and medical endoscopes
- Confocal microscopy / OCT
- Fluorescence microscopy
- Barcode reading
- Object measurement / triangulation
- 3D cameras, LIDAR
- Object recognition / 1D and 2D light curtains
- Spectroscopy
- Laser marking and processing of materials
- Laser wavelength modulation
- Laser projection / display
- Linear scanning
- Optical vibration compensation, e.g. hand-held laser
- craniotome
- Beam positioning / trajectory tracking
- Material marking / material processing

Excellent mechanical and optical properties

All mechanically stressed elements are defined in a single-crystal silicon functional layer and fabricated on a BSOI substrate in a volume micromechanical manufacturing process. This material is characterized by excellent elastic and fracture mechanical properties. In particular, no fatigue phenomena occur during operation due to its single crystallinity. The standard manufacturing process and the design process accompanied by FEM simulations guarantee the following properties:

- High mechanical stability
- (> 2500 g shock resistance)
- High static planarity (radius of curvature > 5 m)
- High dynamic planarity (typically better than λ / 20)

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