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University of Brescia
Department of Electronics for Automation

Contactless Excitation of MEMS Resonant Sensors by Electromagnetic Driving

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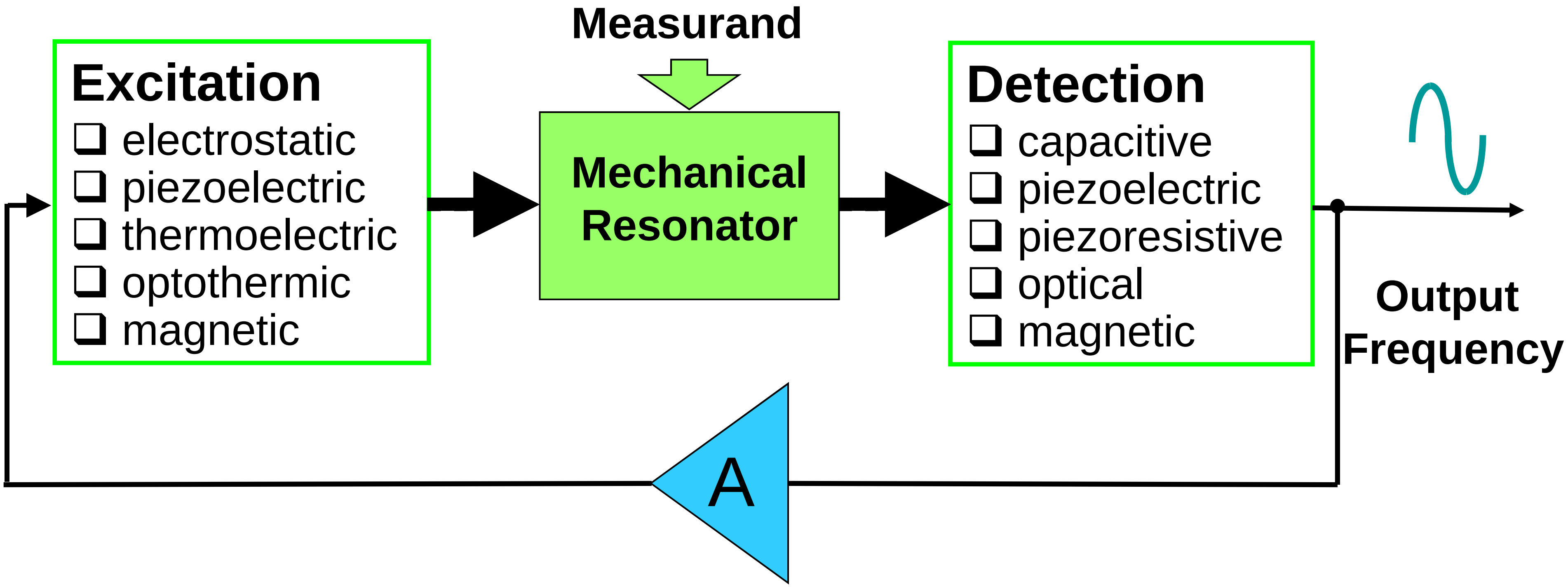
- Introduction
- The magnetic excitation principle
- Application to miniaturized resonators
- Application to MEMS resonators
- Conclusions

Introduction



Measurand

Excitation
- electrostatic
- piezoelectric
- thermoelectric
- optothermic
- magnetic

Mechanical Resonator

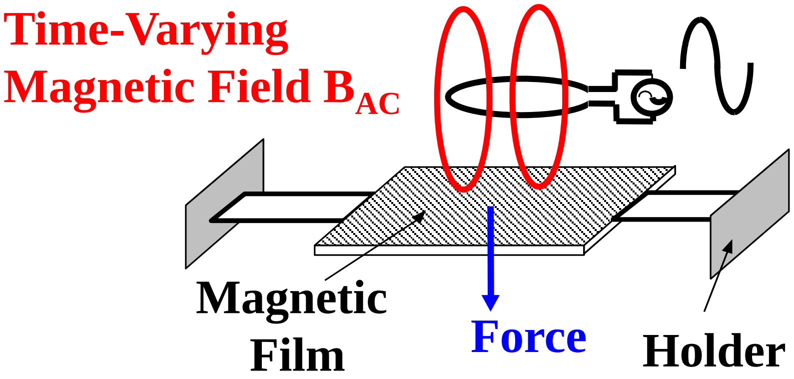
Detection
- capacitive
- piezoelectric
- piezoresistive
- optical
- magnetic

Output Frequency

- Applications that do not allow for cabled solutions
- Applications in environments incompatible with active electronics
- Mechanical resonator sensors are in principle suitable:
  - The resonant approach is robust
  - The resonant frequency does not depend on the detection technique adopted

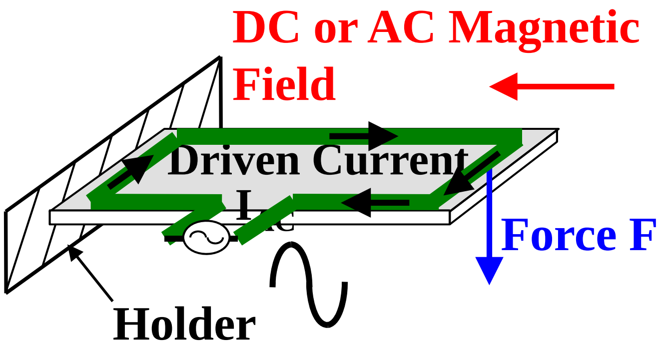
Contactless Magnetic Excitation

Magnetic Films



Incompliant with traditional microfabrication process

Driven Currents

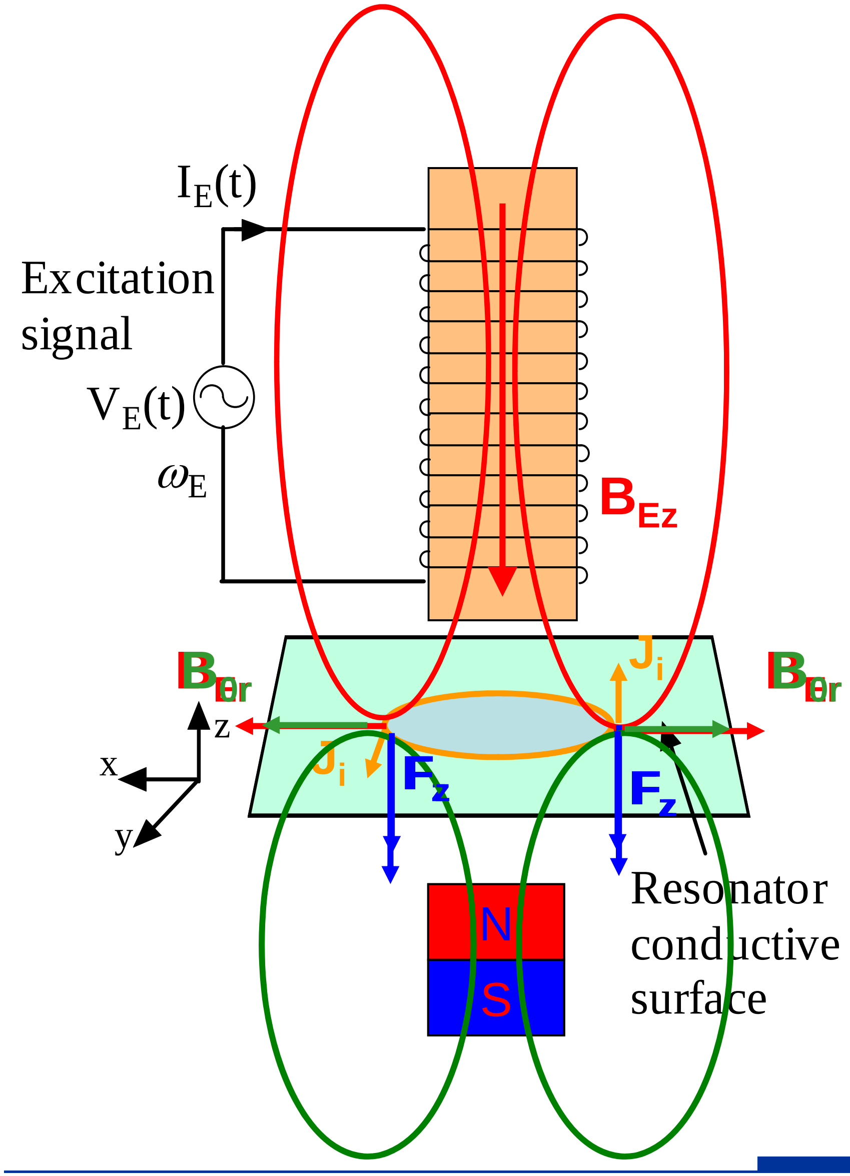


Unsuitable for contactless operation

Proposed Approach

- ❑ **Contactless** excitation of **mechanical resonances** in microstructures
- ❑ Exploitation of the interaction between external DC or AC magnetic field with AC currents inductively coupled to the resonator
- ❑ No specific magnetic property is required
- ❑ The resonators are required to be only **electrical conductive**

The excitation principle



Without static magnetic field

$$F_z(t) = \frac{1}{2} J_i(\omega_E) B_{Er} \left[\sin(\phi) + \sin(2\omega_E t + \phi)\right]$$

- $J_i(\omega_E)$: current density onto the resonator surface.
- B_{Er}: radial component of the excitation magnetic field.
- ϕ: Phase difference between the force F_z and the current I_E caused by the impedence of the resonator surface.

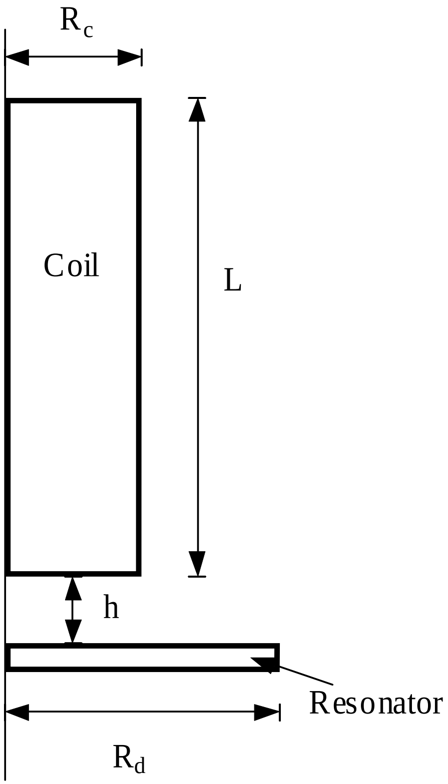
With static magnetic field

$$F_z(t) = \frac{1}{2} J_i(\omega_E) \left[B_{Er} \sin(\phi) + B_{0r} \sin(\omega_E t + \phi)\right]$$

- B_{0r}: radial component of the excitation magnetic field.

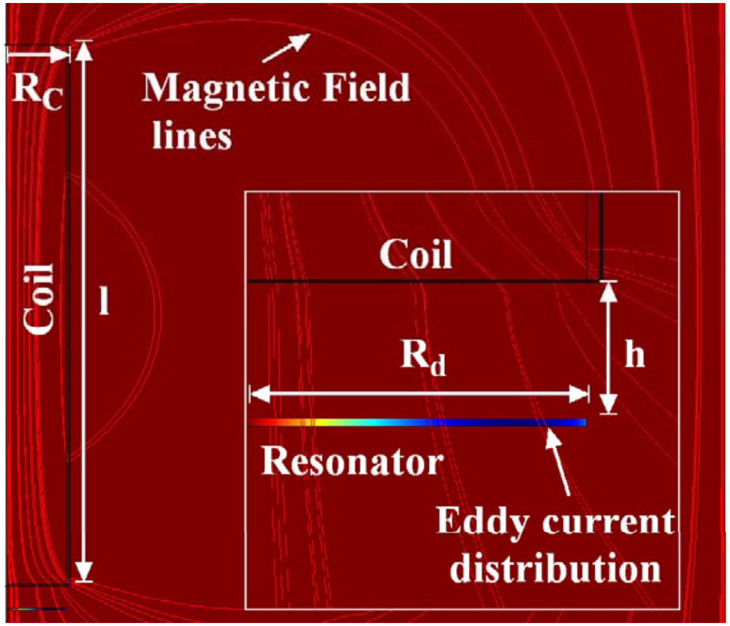
Simulation of the excitation principle

Vertical force



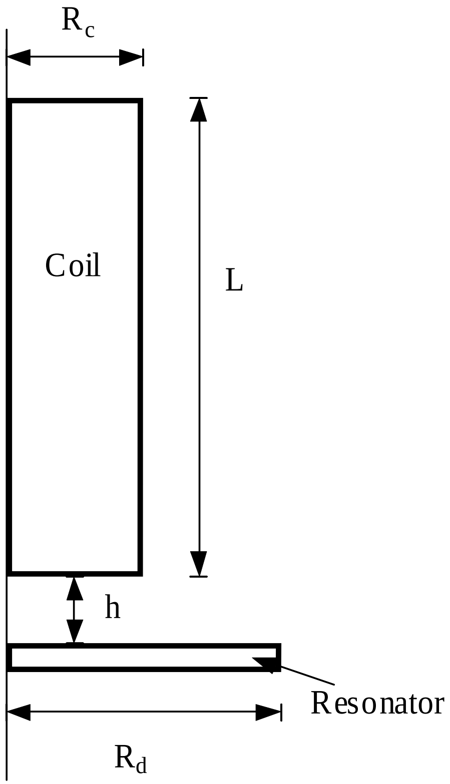
- Coil radius R_c=2.5 mm
- Distance h=5 mm
- Maximum of the force for R_d=5 mm

- Axial symmetry geometry
- AC Simulation
- Evaluation of
    - Trend of the magnetic field
    - Magnitude of the induced eddy current
    - Magnitude of F_z component of force



Simulation of the excitation principle

Vertical force



- Coil radius R_c=2.5 mm
- Distance h=5 mm
- Maximum of the force for R_d=5 mr

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  - Trend of the magnetic field
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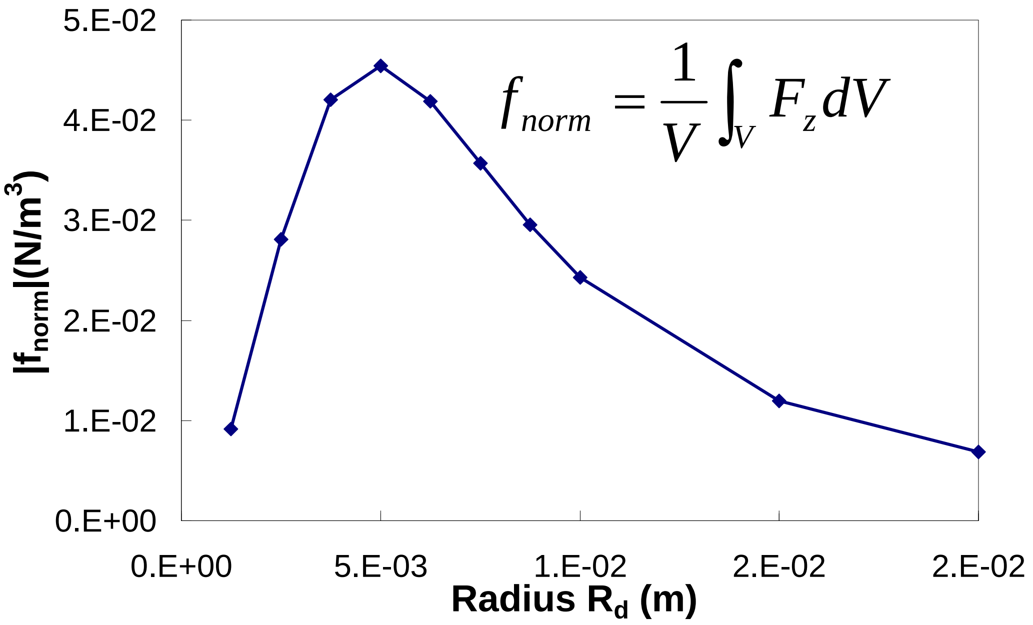
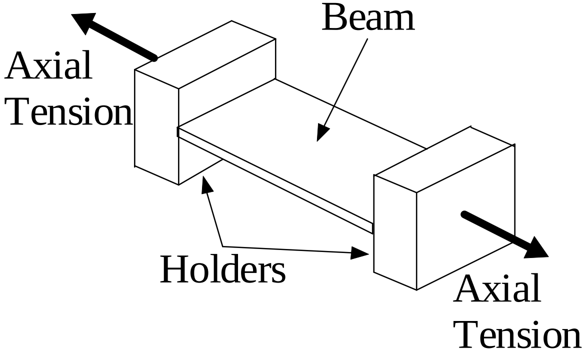
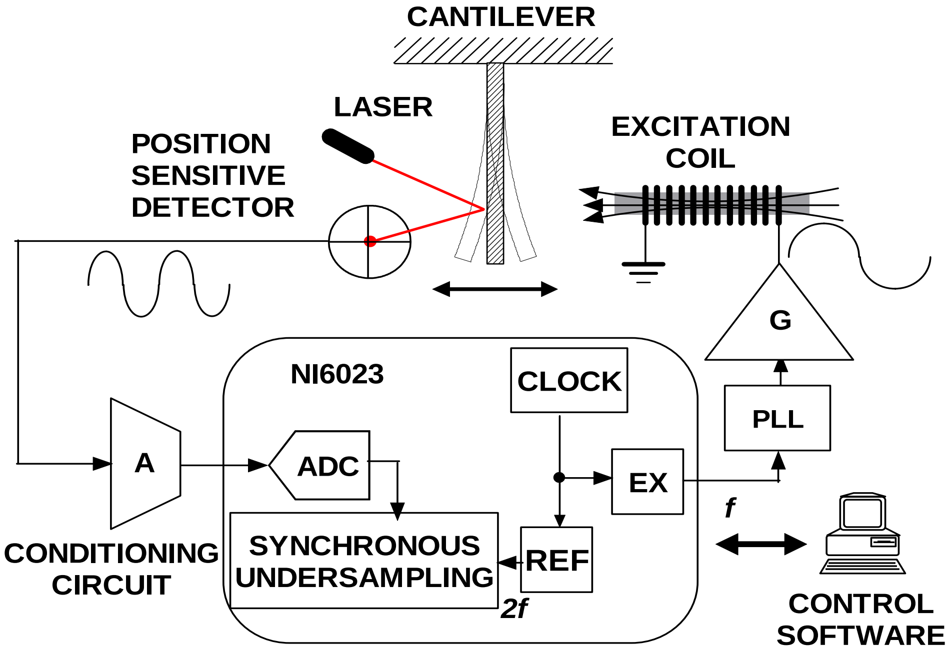


Experimental results on miniaturized resonators

Clamped-clamped resonator





- Clamped-clamped titanium beam
- Titanium parameters:$E=105 \times 10^{9}\ Pa$, $\rho=4940\ kg/m^{3}$, $\sigma=7.407 \times 10^{5}\ S/m$
- Dimensions: 17 mm x 1.4 mm x 100 µm
- Excitation: 35 V (rms)/ 26 mA (rms)
- Excitation distance: 2 mm
- Optical system for the frequency characterization of resonators

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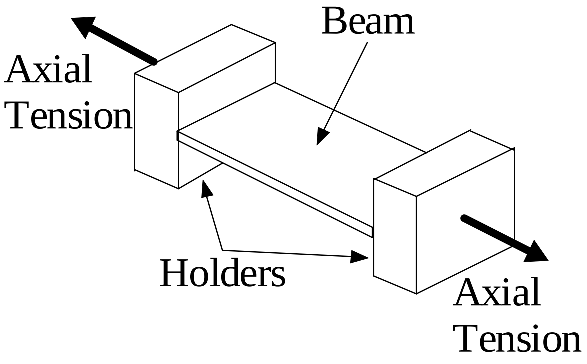

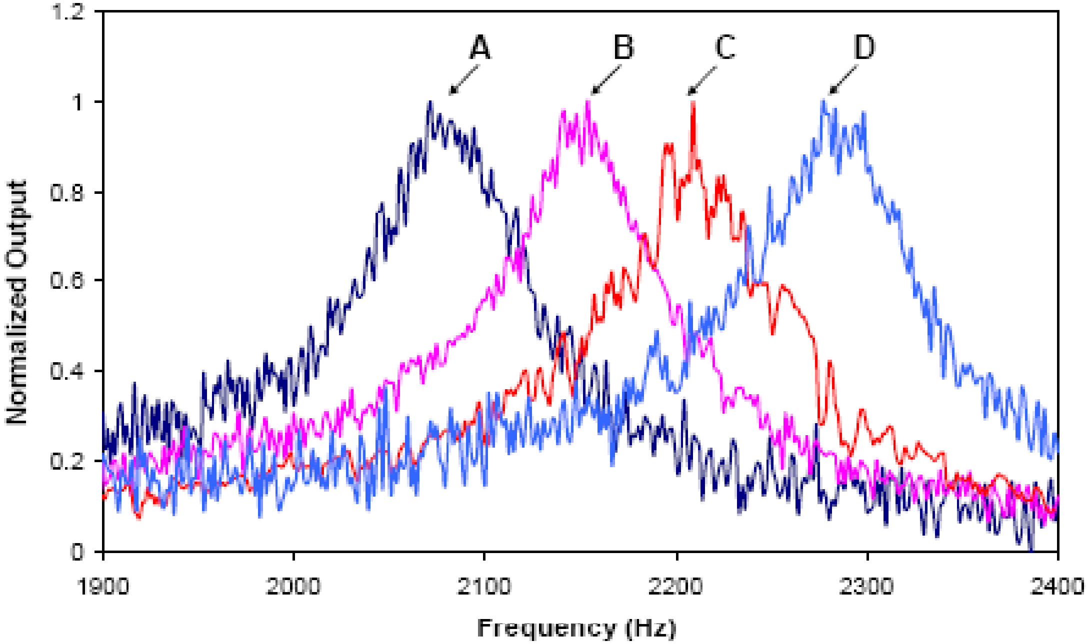

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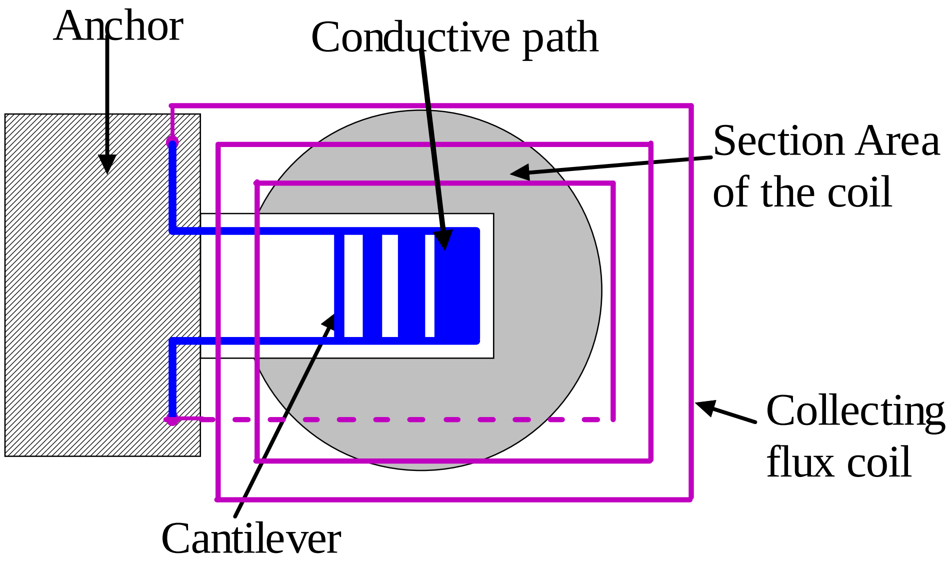
MEMS Design

Effects of the downscaling of the dimensions of the resonators

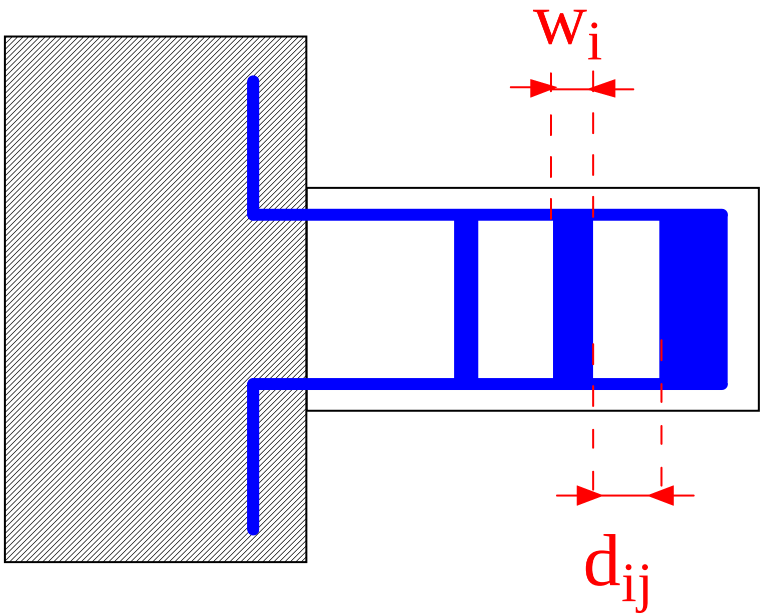
- ❑ Reduction of the total magnetic flux linked to the structures
  - ❑ Decrease of the induced eddy-current density
  - ❑ Decrease of the Lorentz force
- ❑ Increase of the mechanical stiffness



Proposed solution: conductive path on the surface of the cantilever

- ❑ Connection with a collecting flux coil
- ❑ Multiple transversal paths for the distribution of the circulating currents

Simulation of MEMS devices

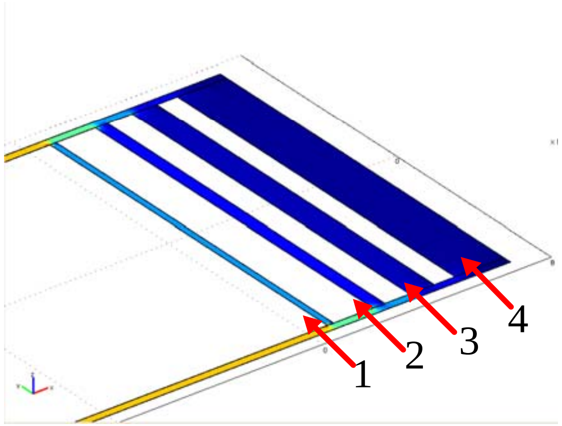


- ☐ Design of the conductive paths:
    - ☐ Choice of width w_i and reciprocal distance d_{ij}
    - ☐ Constraint of equal distribution of the circulating current in each path

$$f_{ris} = \alpha \frac{h}{L^2}\sqrt{\frac{E}{\rho}}$$

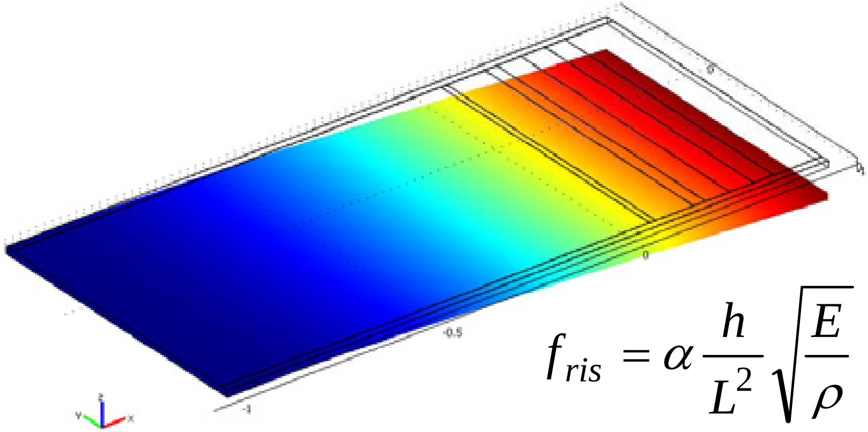
Simulation of MEMS devices

- Design of the conductive paths:
  - Choice of width w_i and reciprocal distance d_{ij}
  - Constraint of equal distribution of the circulating current in each path
- AC electrical simulation with unity current impressed
- Computation of the current in the transversal paths



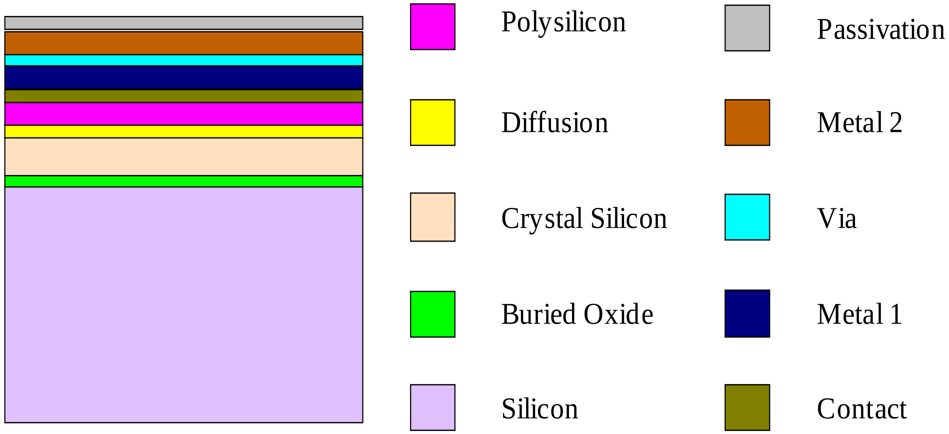
N	I(A)
1	0.267
2	0.249
3	0.251
4	0.233

- Estimation of the resonant frequencies of the structures with the conductive paths
- Simulation for a 1500 x 700 x 15 µm cantilever
- Value from the theoretical predictions: 9200 Hz
- Value from the simulation: 9404 Hz



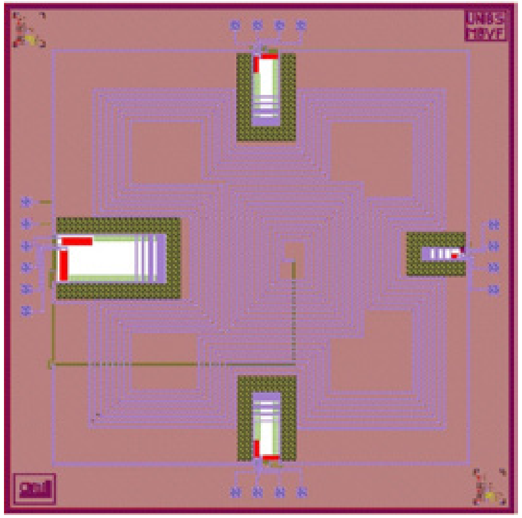
$$f_{ris} = \alpha \frac{h}{L^2} \sqrt{\frac{E}{\rho}}$$

Fabrication of MEMS devices

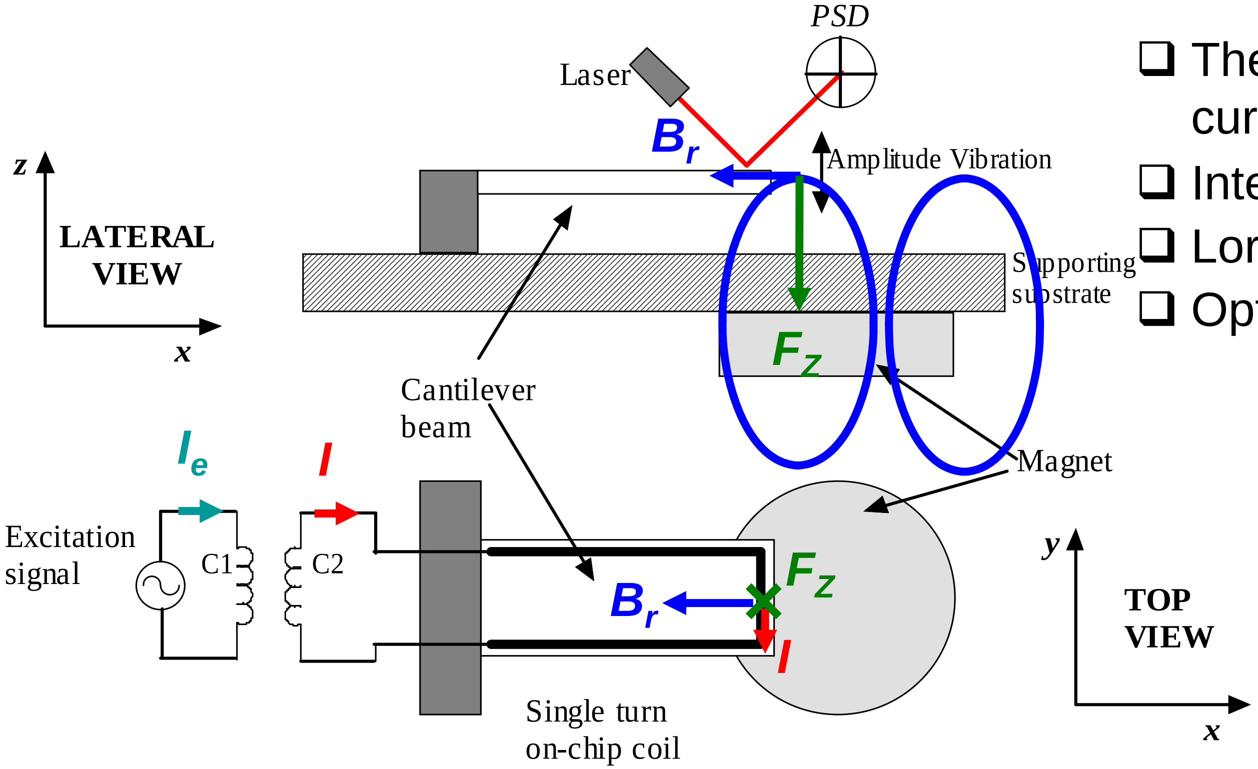


- Process of the CNM (Centro Nacional de Microelectronica) of Barcellona
- Bulk-micromachining process
- 450 µm-thick N-doped BESOI (*Bond and Etch back Silicon on Insulator*) substrate with <100> orientation
- 5 photolithographic masks (1 polysilicon, 2 metals)

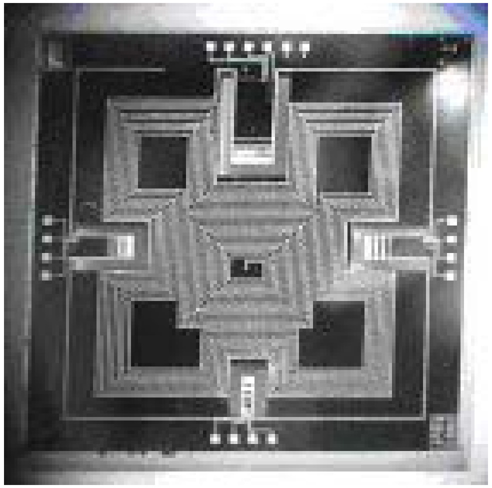
- Die with 4 cantilever
- On-chip conductive paths
- On-chip collecting flux coil
- Half-bridge configuration of polysilicon piezoresistor



Experimental results on MEMS resonators



- The current I_e induces the current I
- Interaction of I with B_r
- Lorentz force F_z
- Optical system



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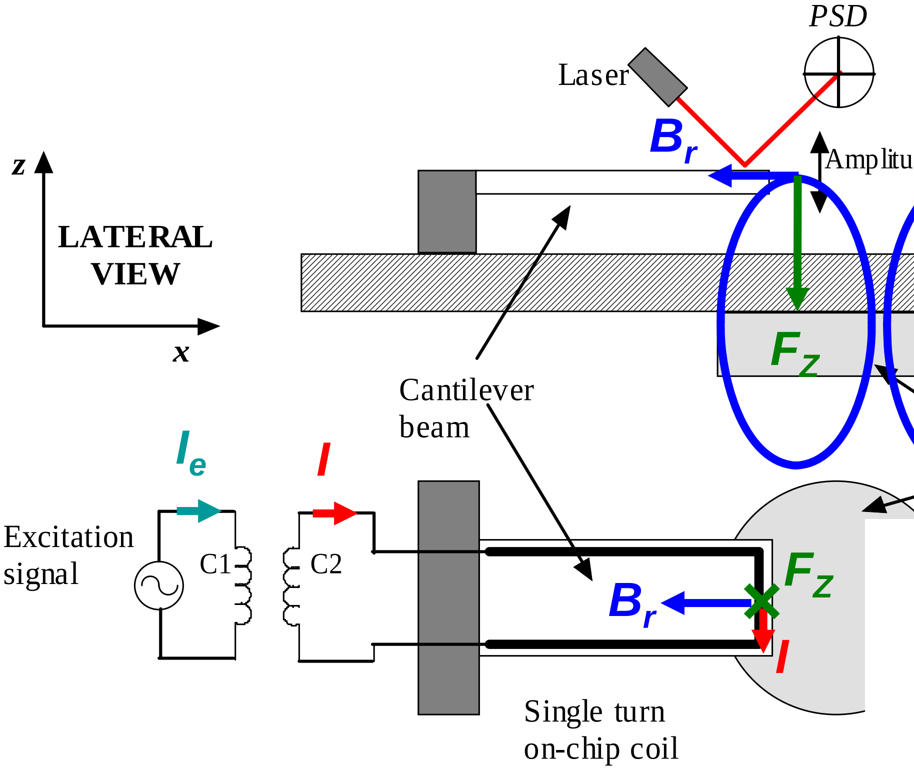

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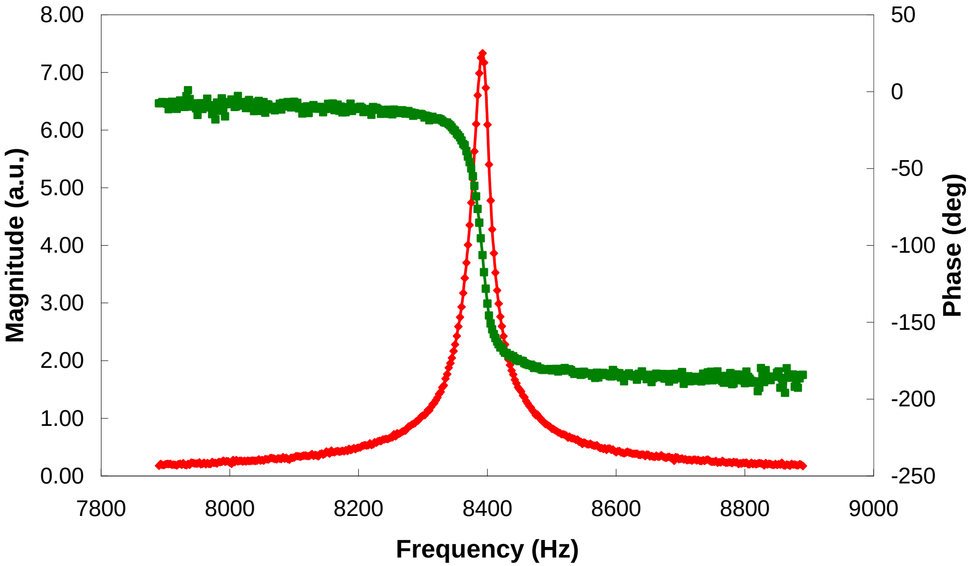

- Contactless Magnetic Excitation
- Excitation coil C1: L=9.8 mH
- Excitation current : 200 mA
- Coil C2: L=5.3 mH
- Magnet: 1.4 T
- Distance C1-C2: 8 mm

Conclusions

- Contactless excitation of miniaturized resonators by means of magnetic fields has been proved
- The effects of the downscaling of the dimensions of the resonators on the excitation principle have been analyzed
- Dedicated solutions have been studied and applied to the design of MEMS microresonators
- Contactless excitation of MEMS microresonators by means of magnetic fields has been proved
- The principle can be adopted to excite contactless sensors operating on short-range excitation distance of the order of 1 cm
- The experimental activity is investigating the possibility of extending the principle to vibration readout
- Contactless excitation and detection of vibrations in conductive microstructures can be in general applied to measure a large variety of physical quantities which can cause a predictable shift in the resonant frequency of the structure