



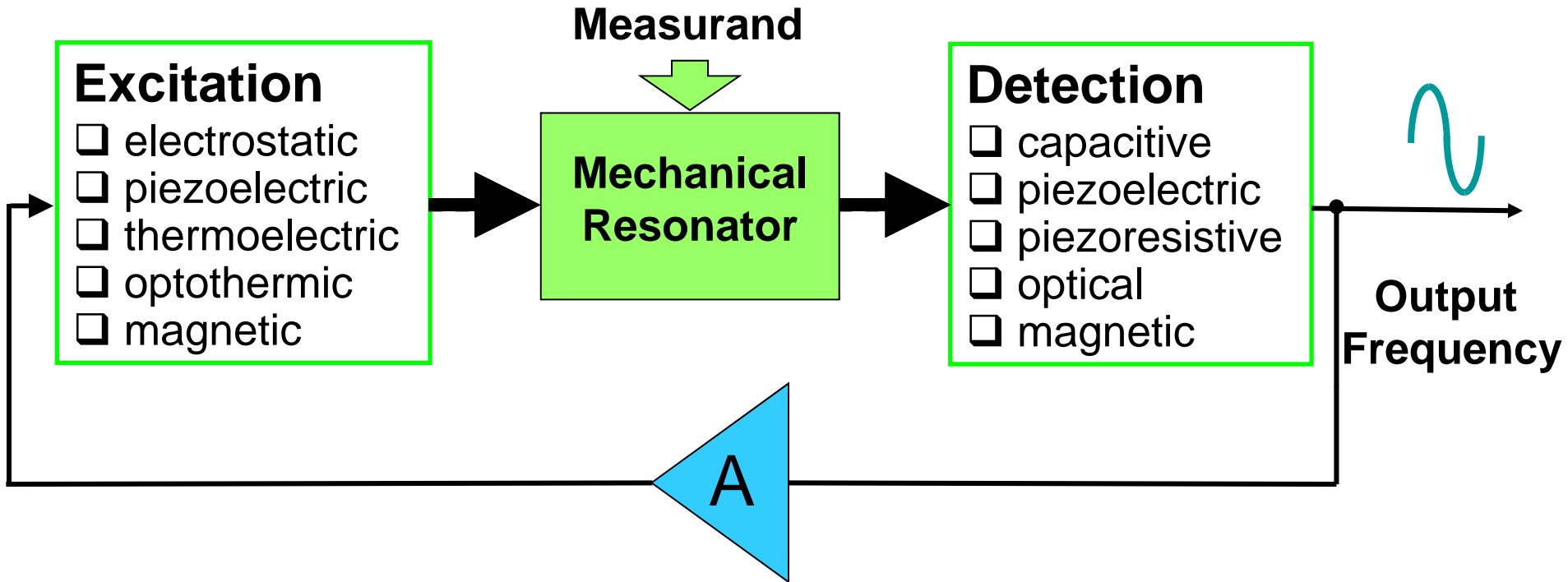
University of Brescia
Department of Electronics for Automation

Contactless Excitation of MEMS Resonant Sensors by Electromagnetic Driving

Marco Baù, V. Ferrari, D. Marioli

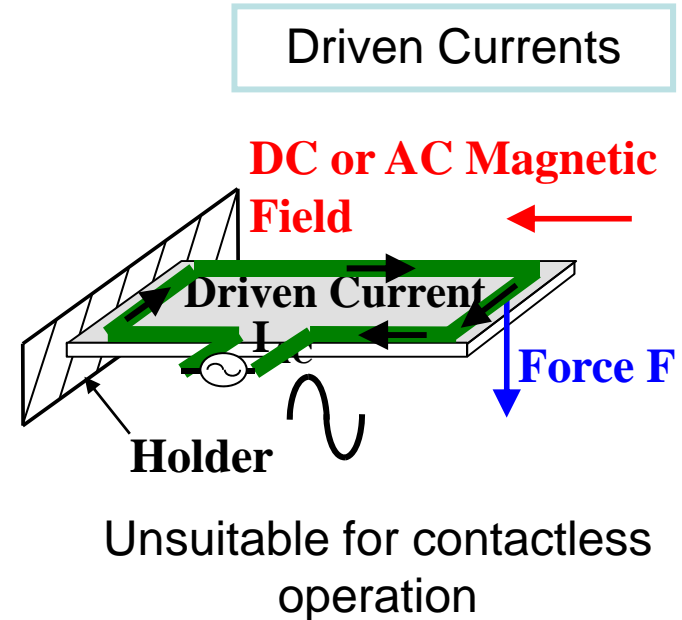
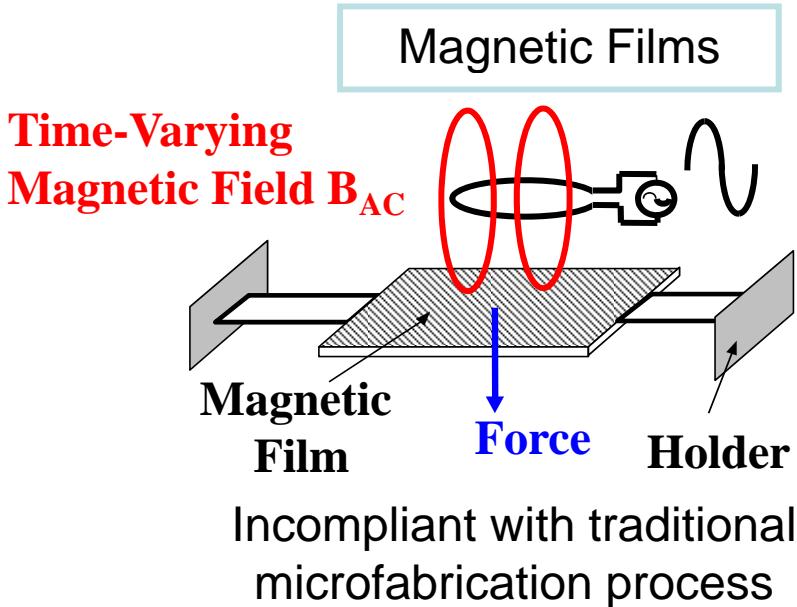
- Introduction
- The magnetic excitation principle
- Application to miniaturized resonators
- Application to MEMS resonators
- Conclusions

Introduction



- 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

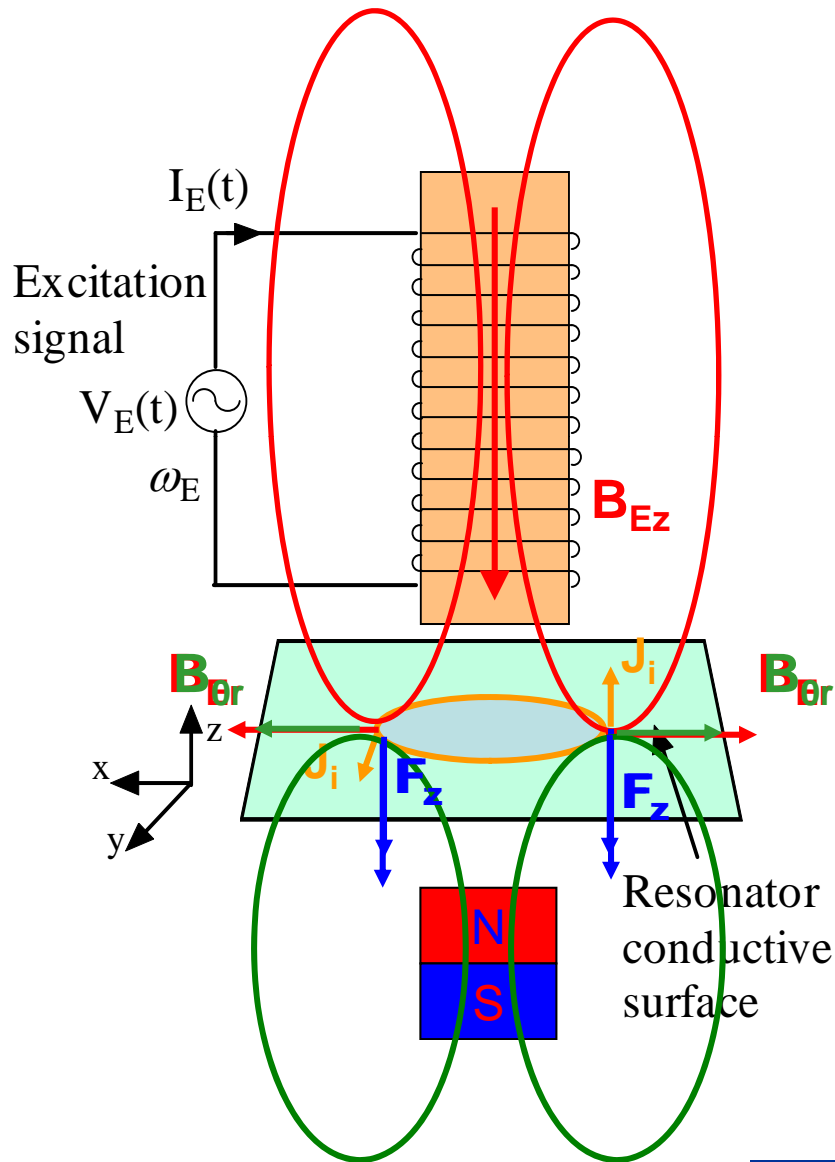
Contactless Magnetic Excitation



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

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

- $J_i(\omega_E)$: 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 impedance of the resonator surface.

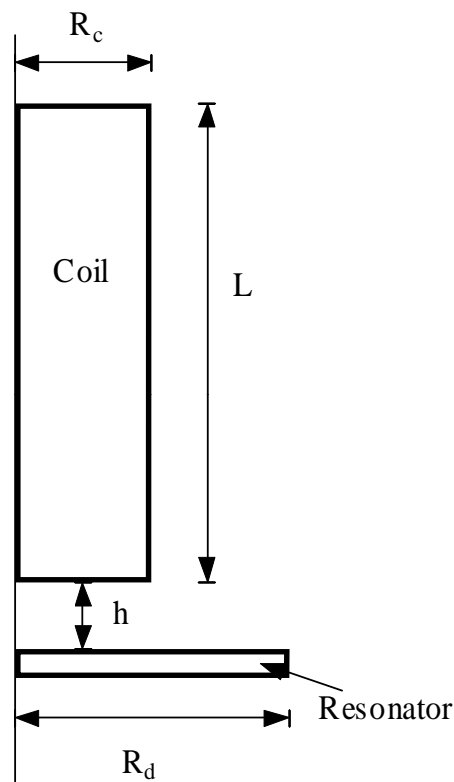
With static magnetic field

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

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

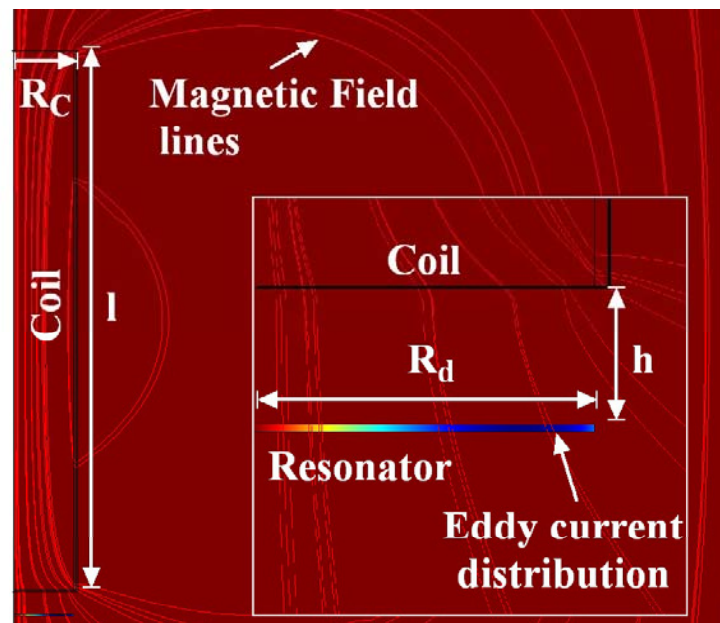
Simulation of the excitation principle

Vertical force



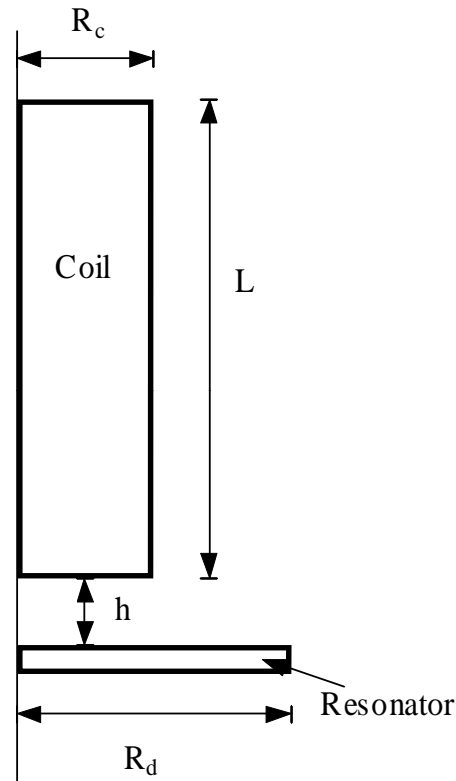
- ❑ Coil radius $R_c=2.5$ mm
- ❑ Distance $h=5$ mm
- ❑ Maximum of the force for $R_d=5$ mm

- ❑ 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



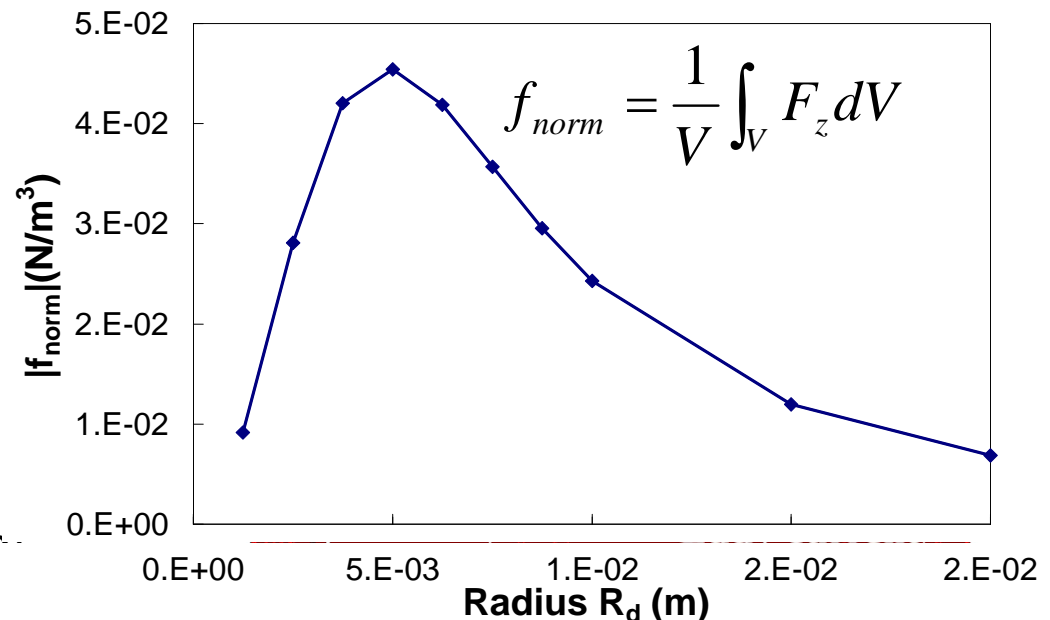
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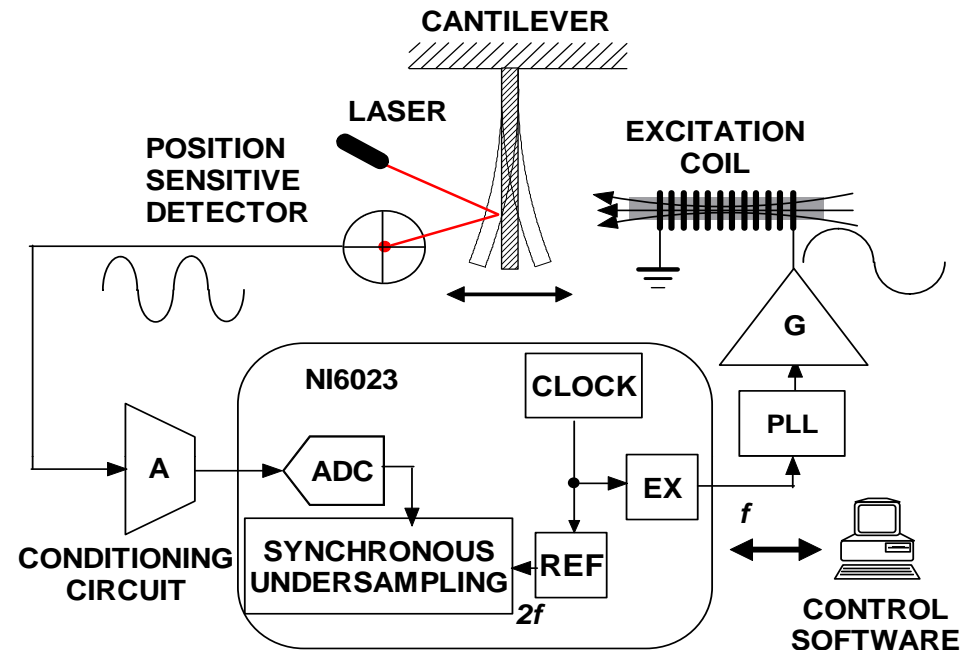
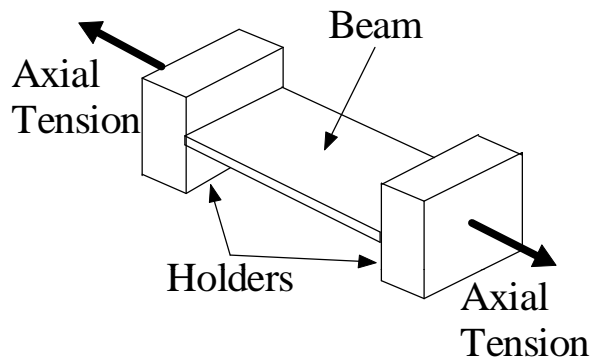
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Experimental results on miniaturized resonators

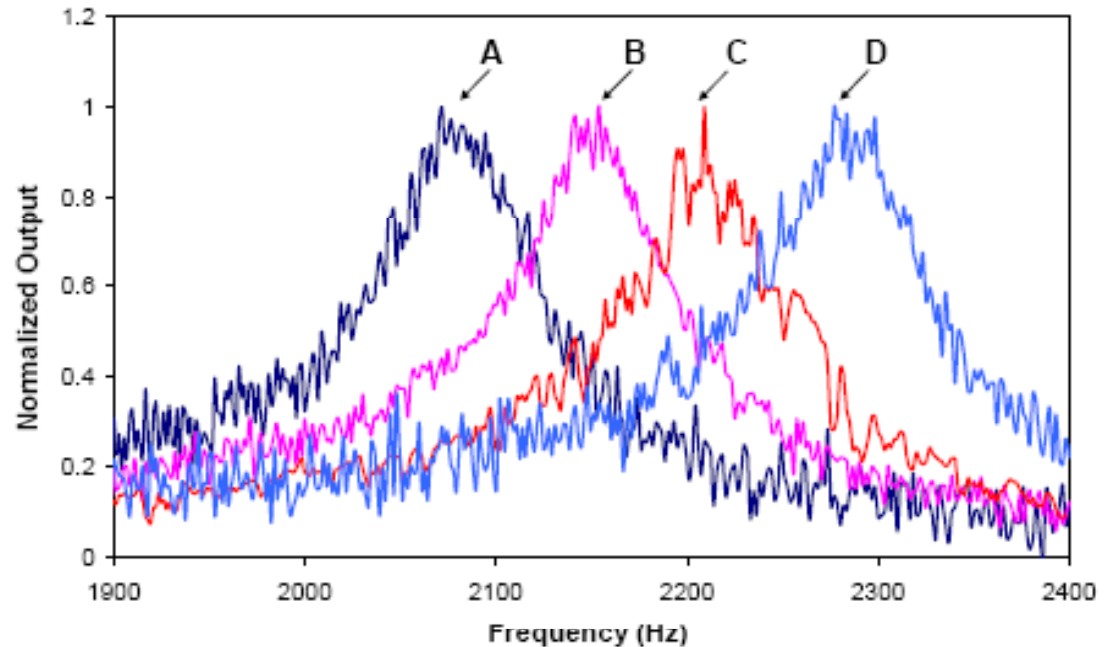
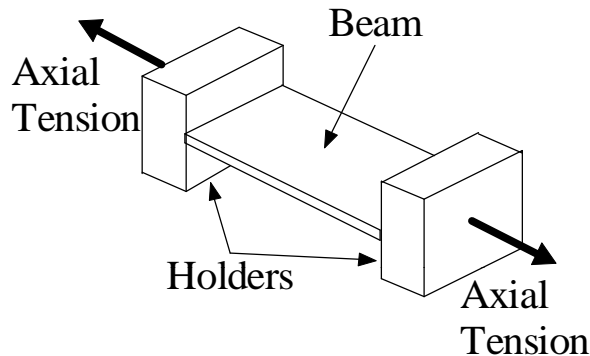
Clamped-clamped resonator



- ❑ Clamped-clamped titanium beam
- ❑ Titanium parameters: $E=105 \times 10^9 \text{ Pa}$, $\rho=4940 \text{ kg/m}^3$, $\sigma=7.407 \times 10^5 \text{ S/m}$
- ❑ 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

Experimental results on miniaturized resonators

Clamped-clamped resonator

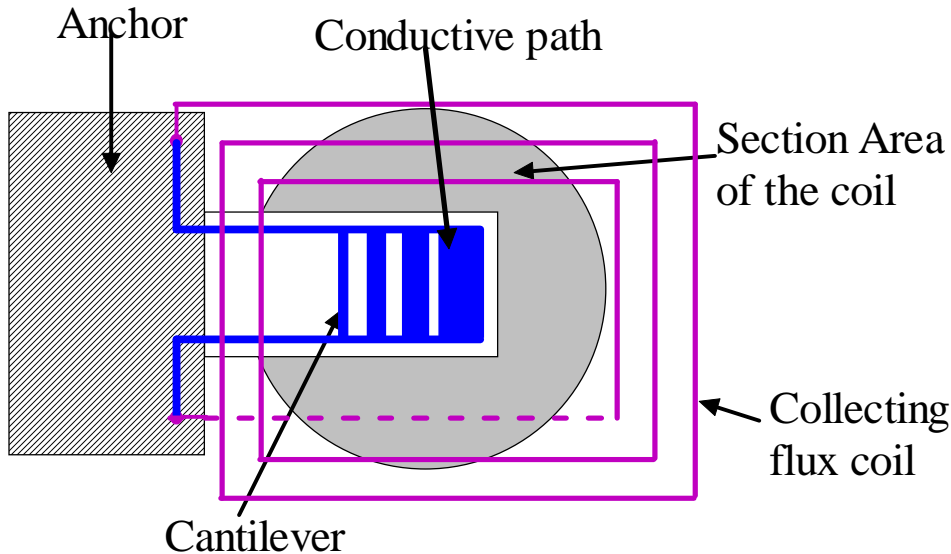


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MEMS Design

Effects of the downscaling of the dimensions of the resonators

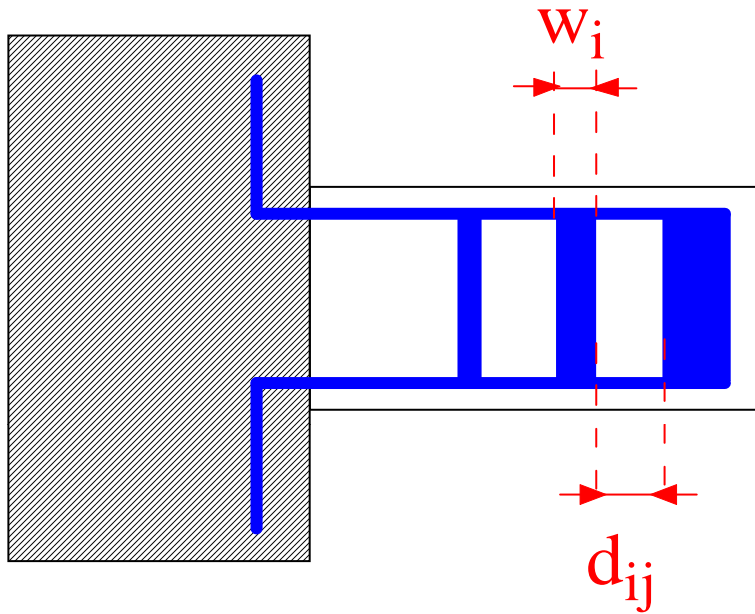
- ❑ Reduction of the total magnetic flux linked to the structures
 - ❑ Decrease of the induced eddy-current density
 - ❑ Decrease of the Lorentz force
- ❑ Increase of the mechanical stiffness



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

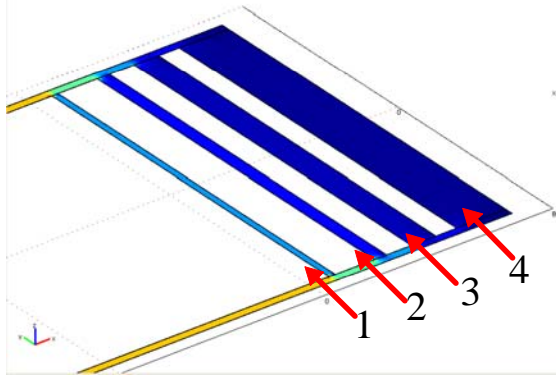
Simulation of MEMS devices



- 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



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

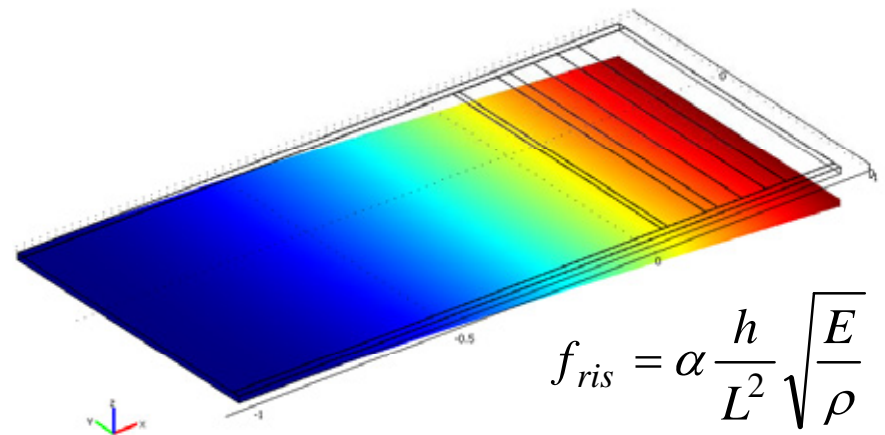
- Design of the conductive paths:
 - Choice of width w_i and reciprocal distance d_{ij}
 - Constraint of equal distribution of the circulating current in each path
- AC electrical simulation with unity current impressed
- Computation of the current in the transversal paths

Estimation of the resonant frequencies of the structures with the conductive paths

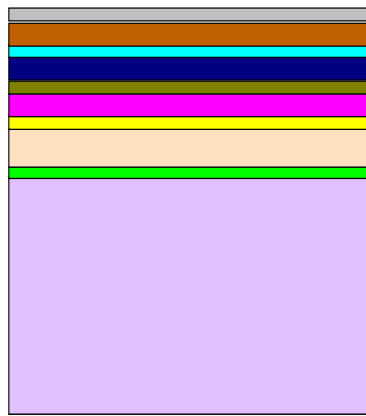
Simulation for a $1500 \times 700 \times 15 \mu\text{m}$ cantilever











Value from the theoretical predictions: 9200 Hz

Value from the simulation: 9404 Hz



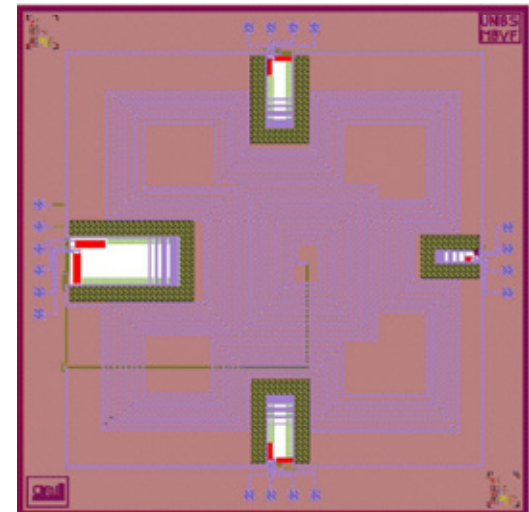
Fabrication of MEMS devices



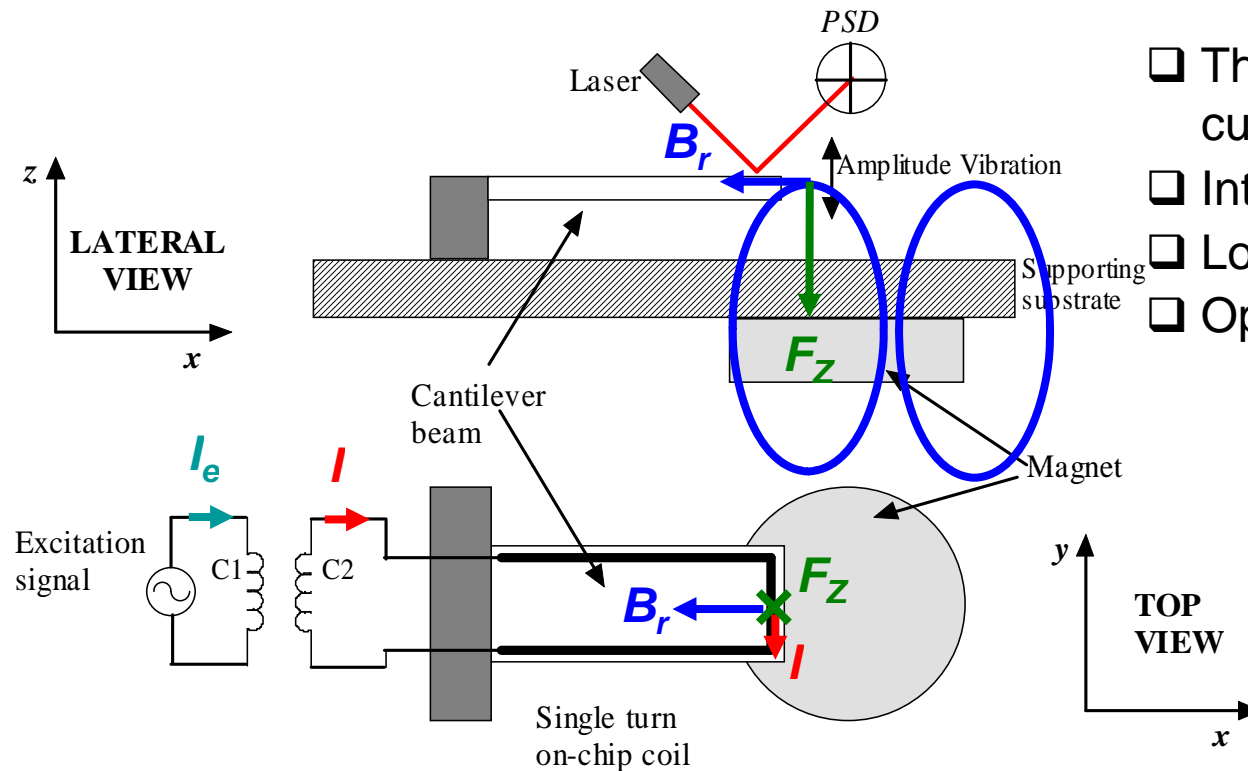
	Polysilicon		Passivation
	Diffusion		Metal 2
	Crystal Silicon		Via
	Buried Oxide		Metal 1
	Silicon		Contact

- ❑ 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 $\langle 100 \rangle$ orientation
- ❑ 5 photolithographic masks (1 polysilicon, 2 metals)

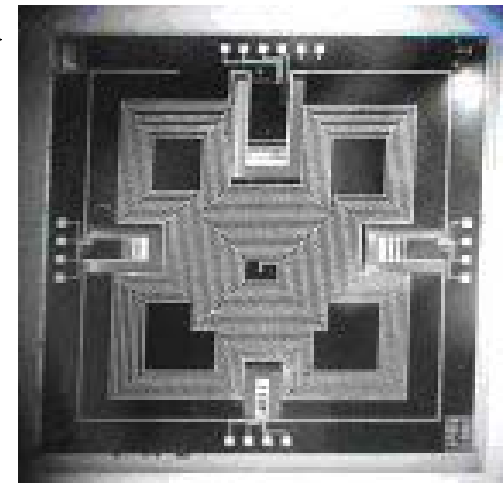
- ❑ Die with 4 cantilever
- ❑ On-chip conductive paths
- ❑ On-chip collecting flux coil
- ❑ Half-bridge configuration of polysilicon piezoresistor



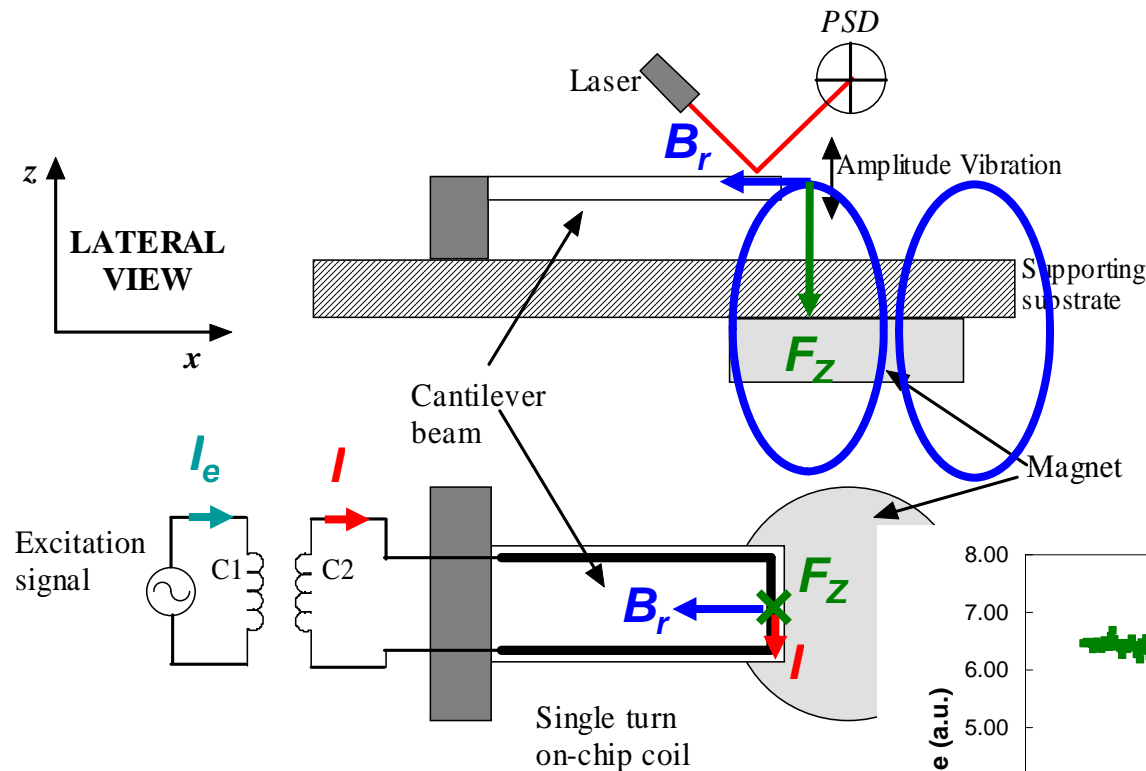
Experimental results on MEMS resonators



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

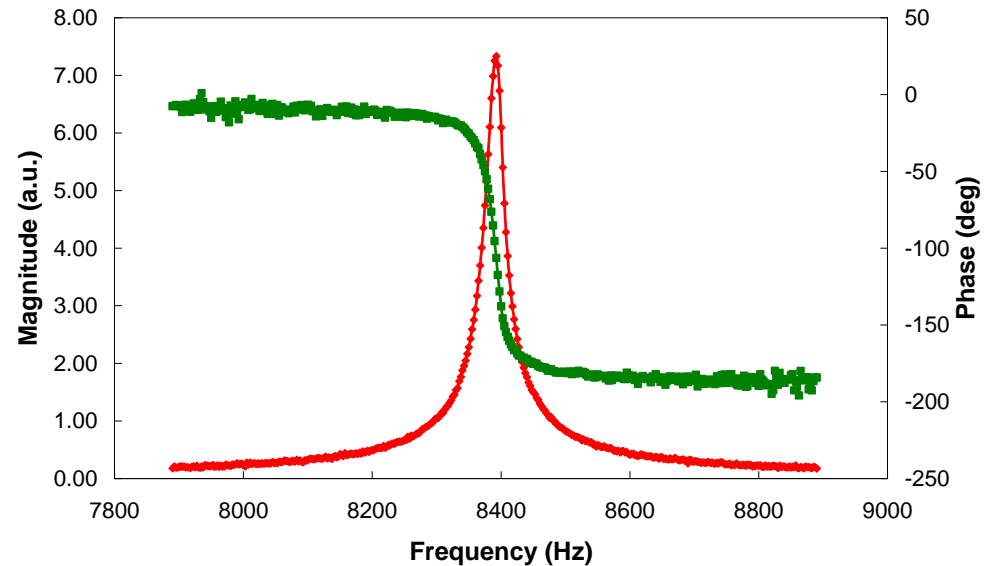


Experimental results on MEMS resonators



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

- 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**