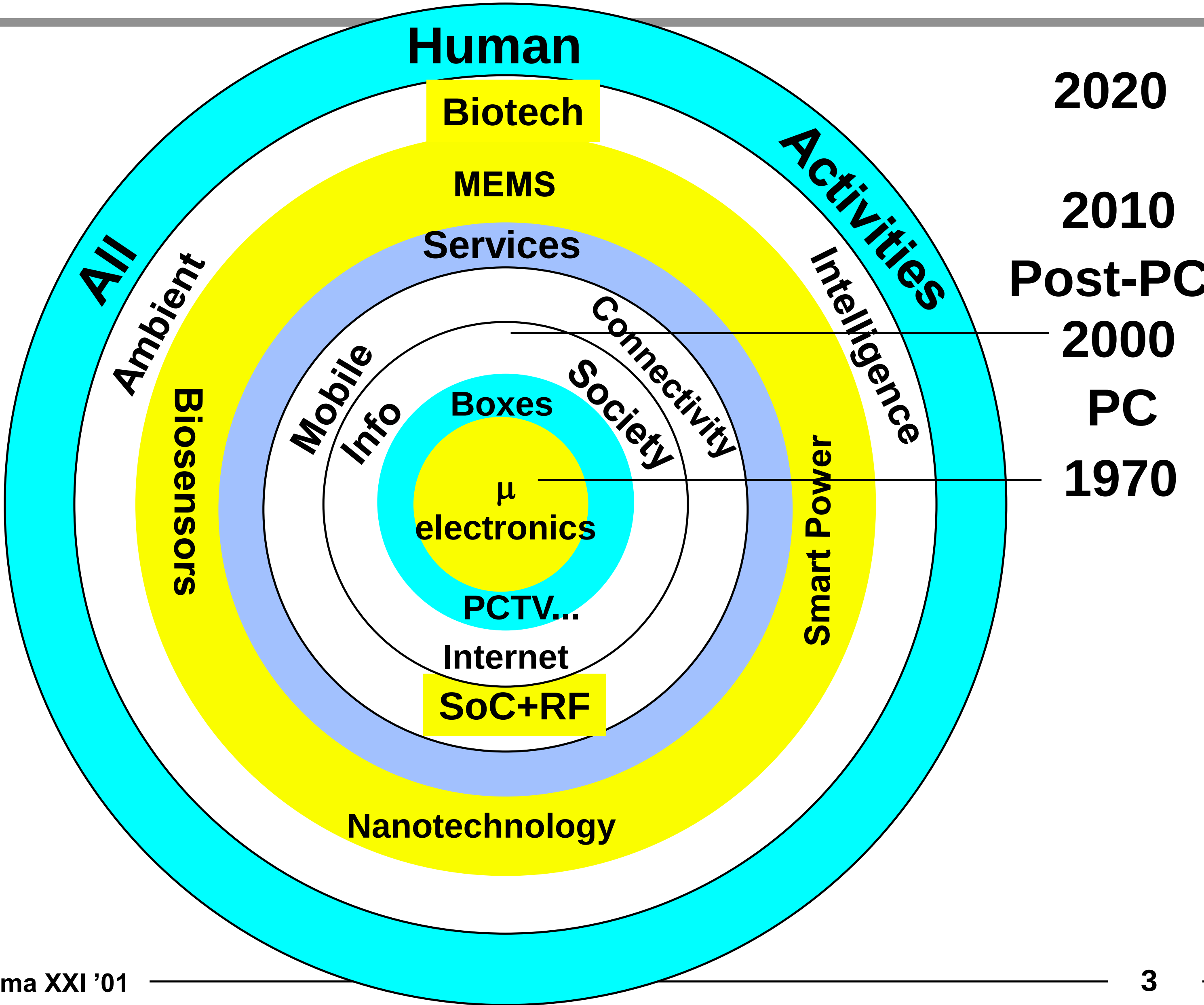
Trends in «More than Moore» and IUNET activity

Andrea L. Lacaita

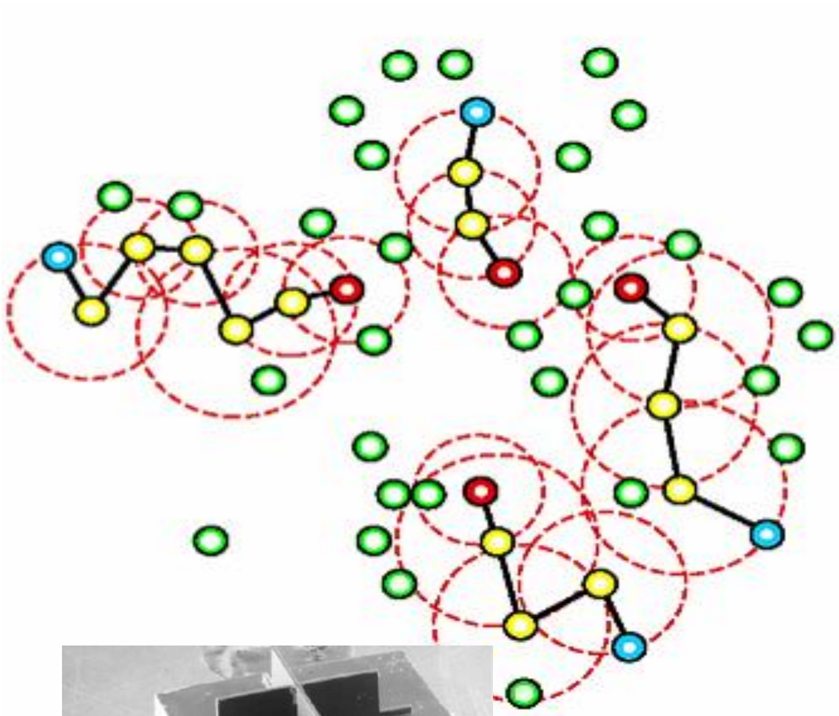
Ouline

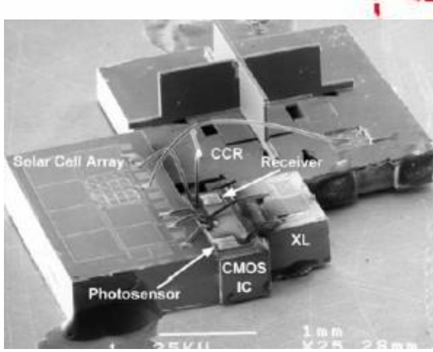
- Pervasion domains: Moore+MtM
- The Italian MEMS «pilot line»
  - LAB4MEMS challenges and results
- Conclusions

The expanding universe of electronics...

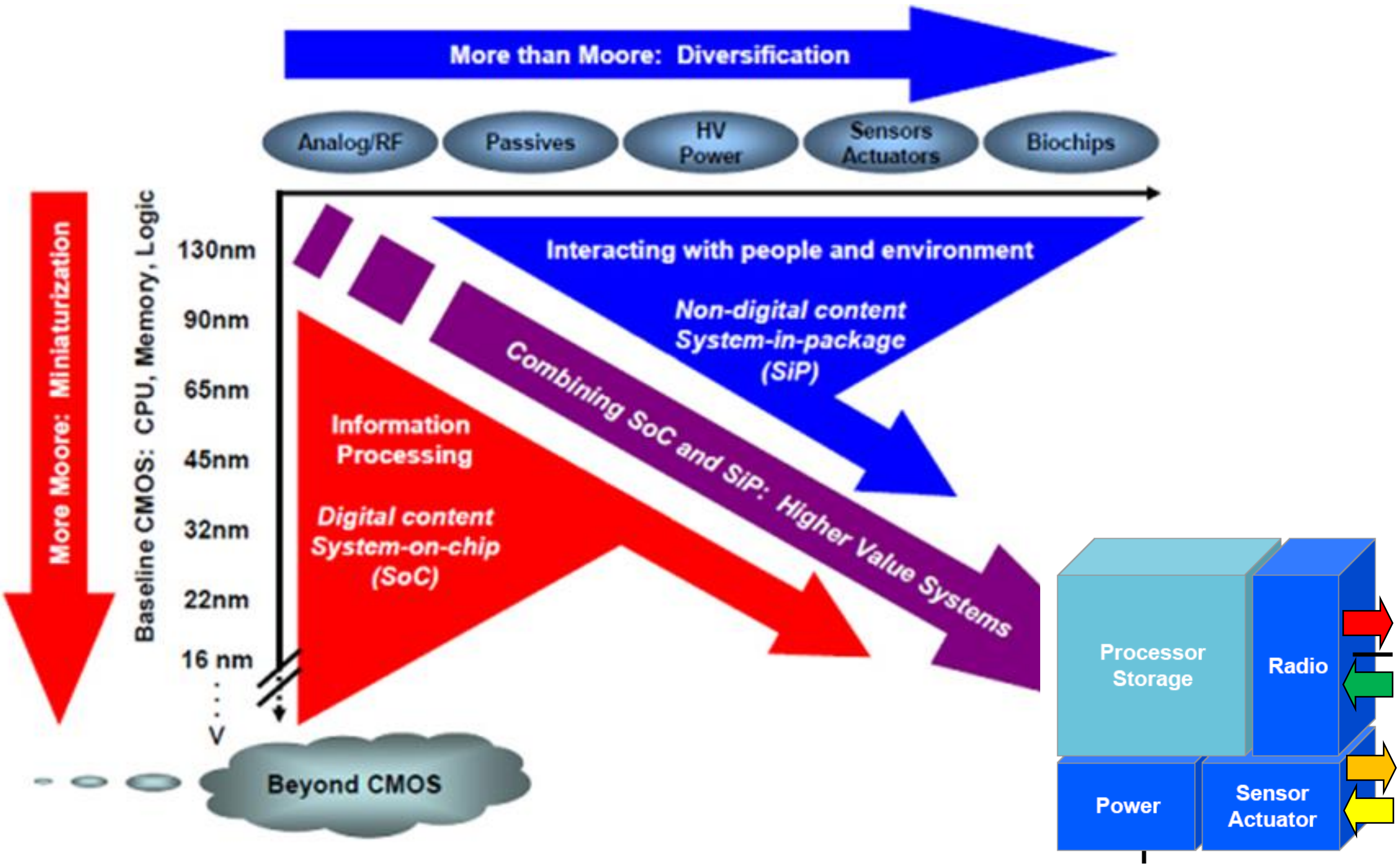


From sensing nodes to cloud





Converging trends



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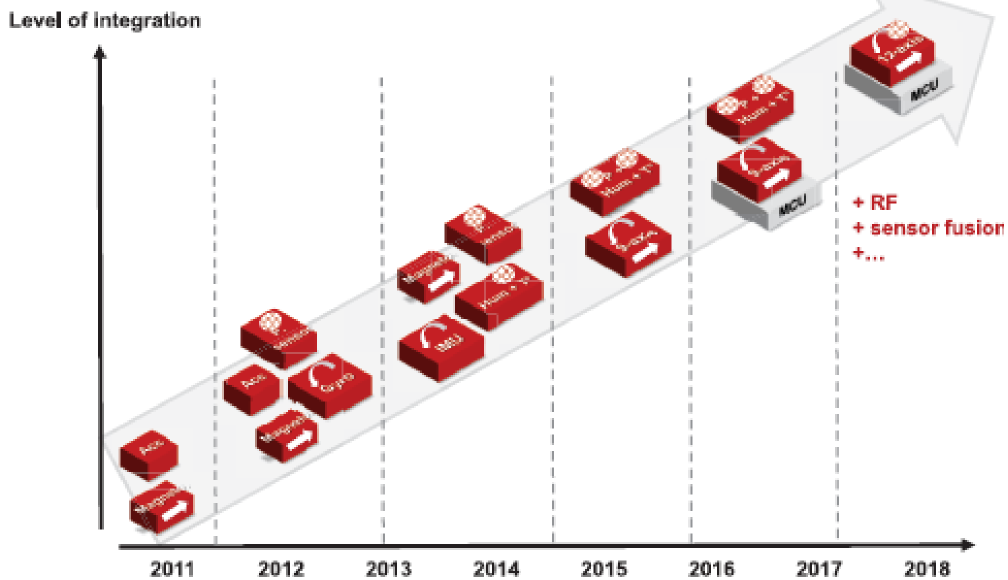
MEMS Market Forecast

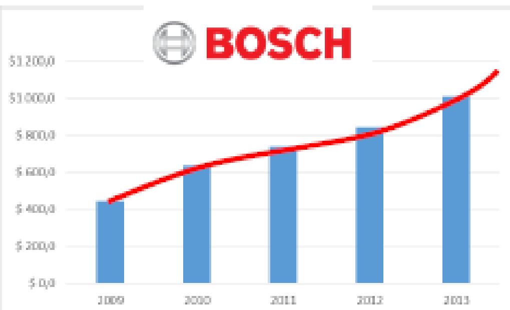


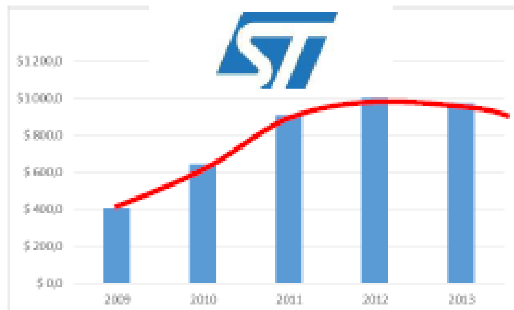
Source: Yole April 2014

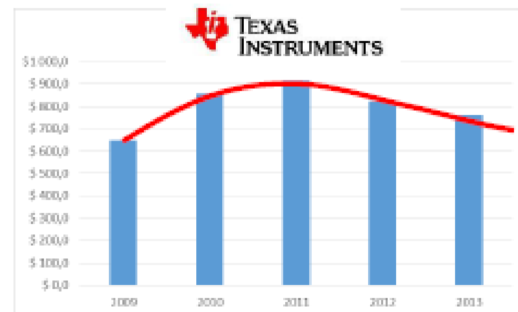
Device	2013-18 CAGR
Micro displays	**57,80%**
Oscillators	**52,70%**
Microfluidics for research	**34,80%**
Inertial combos	**28,40%**
PIR and thermopiles	**23,50%**
Microfluidics for IVD	**23,10%**
Projection systems	**17,70%**
Microdispensers	**16,30%**
Others	**16,10%**
RF MEMS	**15,50%**
Microphones	**13,20%**
Microbolometers	**12,50%**
Other optical MEMS	**10,00%**
Pressure sensors	**7,70%**
InkJet heads	**1,10%**
Accelerometers	**-3,40%**
Gyroscopes	**-3,70%**
Digital compass	**-5,10%**

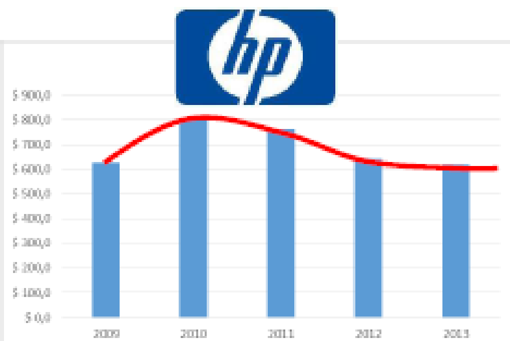
IU.NET

MEMS Market players









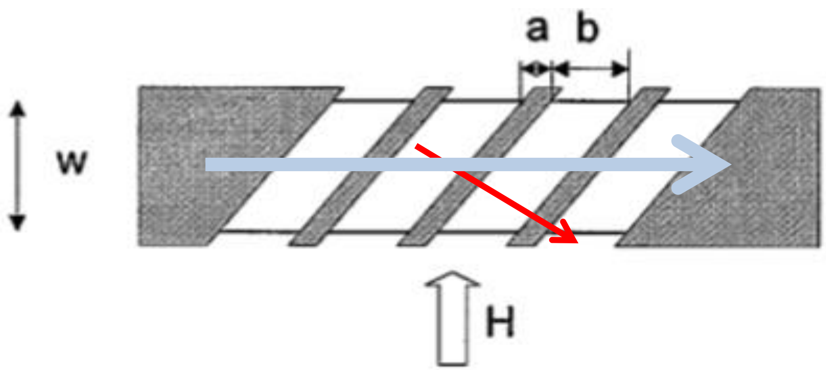
Source: Yole 2014

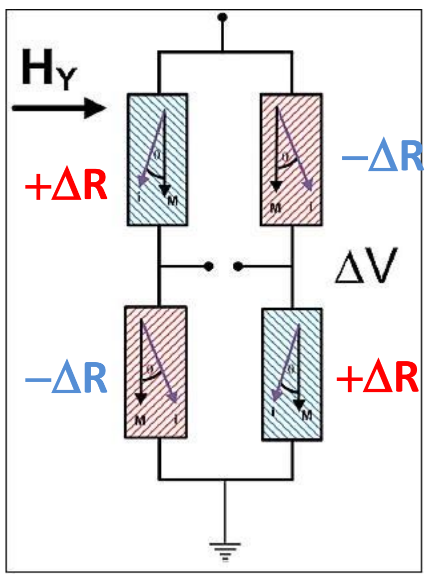
Lab4MEMS

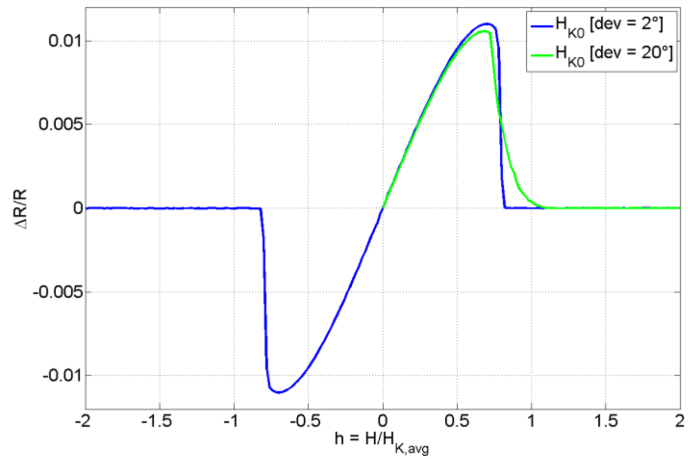
Lab4MEMS aims to establish a European Pilot Line for innovative technologies on **advanced piezoelectric** and **magnetic materials**, including **advanced Packaging** technologies to meet the ever evolving market needs.

Demonstration Device	
Fully integrated print-head	
Piezo electric energy harvester	**UniBO**
Ultrasonic microphones	
AMR Magnetic sensors (3 axis)	**PoliMI**
Lorentz type Magnetometer (3 axis)	**PoliMI**
Photonic Crystal piezo actuator	**UniPi**

Planar AMR devices

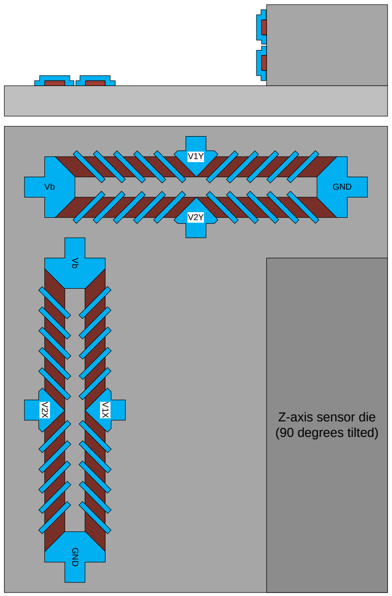


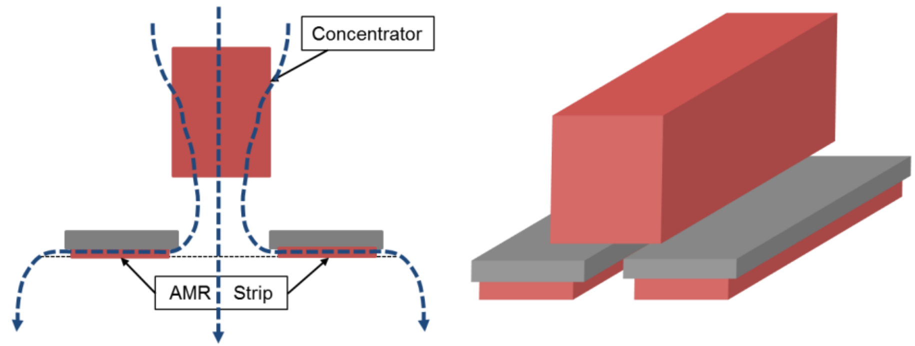


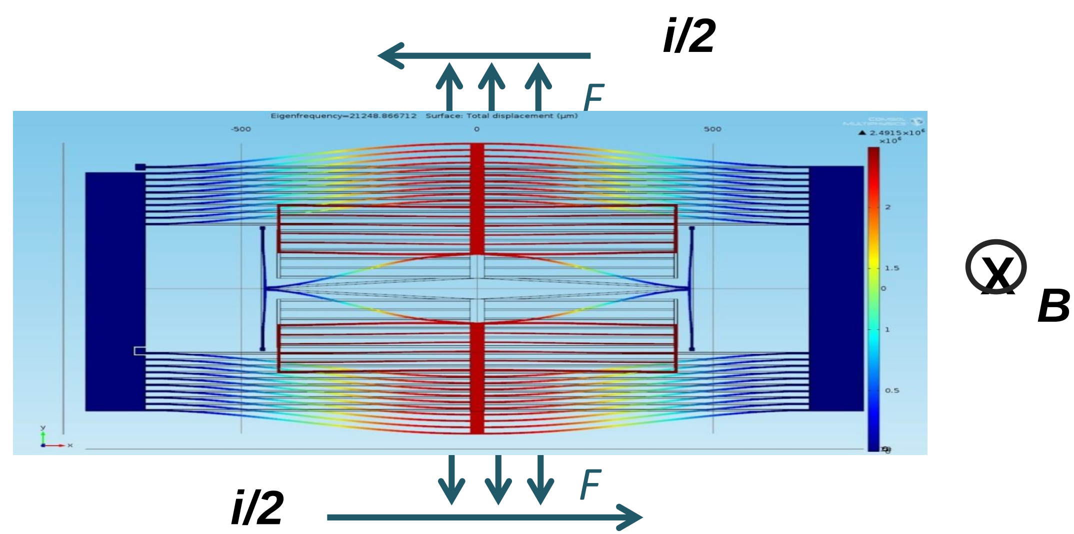


$$\frac{\Delta R}{R_0} = \pm \frac{\Delta \rho}{\rho} \frac{H}{H_k} \sqrt{1 - \left(\frac{H}{H_k} \right)^2}$$

3 axis magnetometers

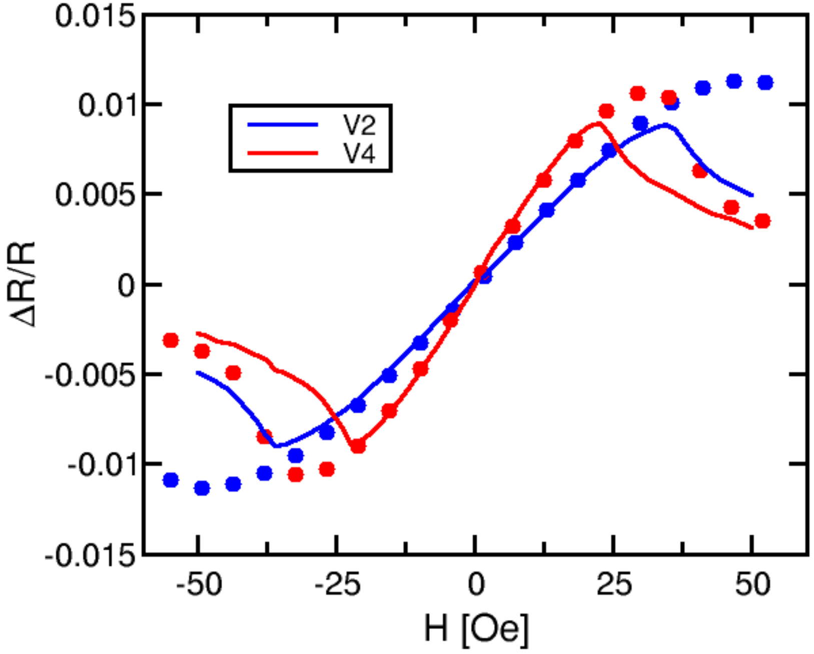




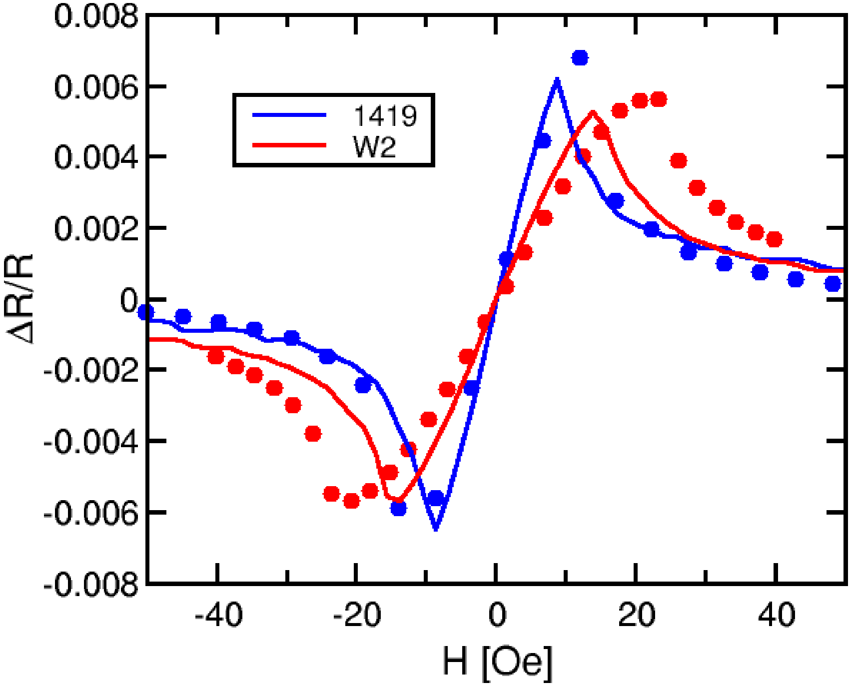


Experimental results and modeling

t = 50nm samples

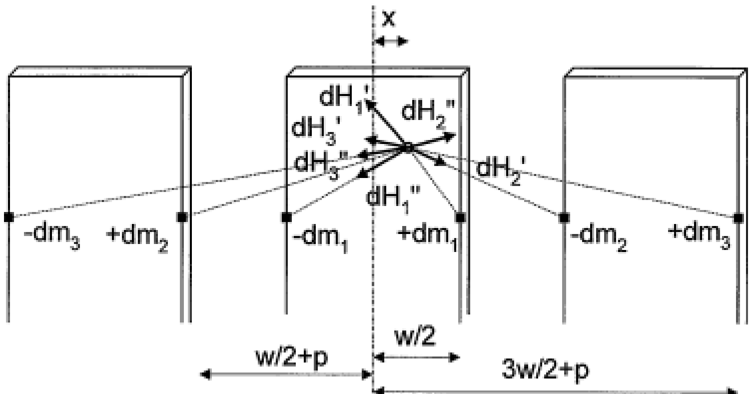


t = 20nm samples

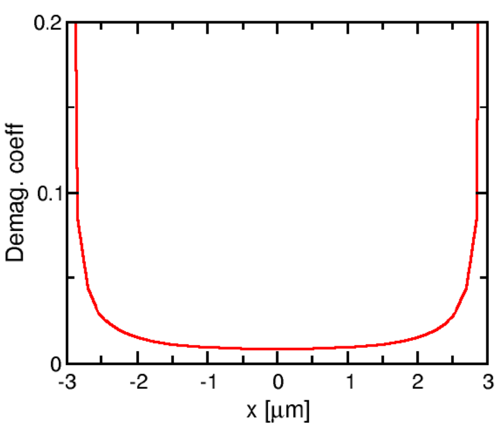


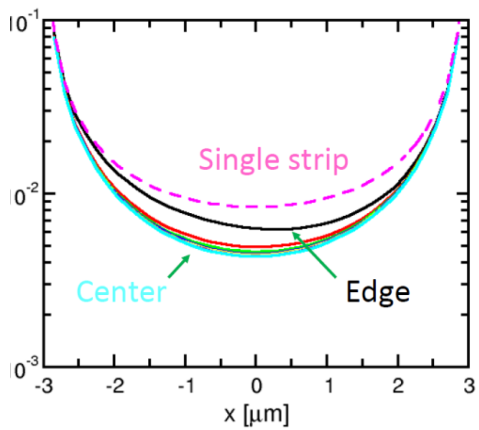
Symbols = exp. data — Lines = sim. results

AMR physical model



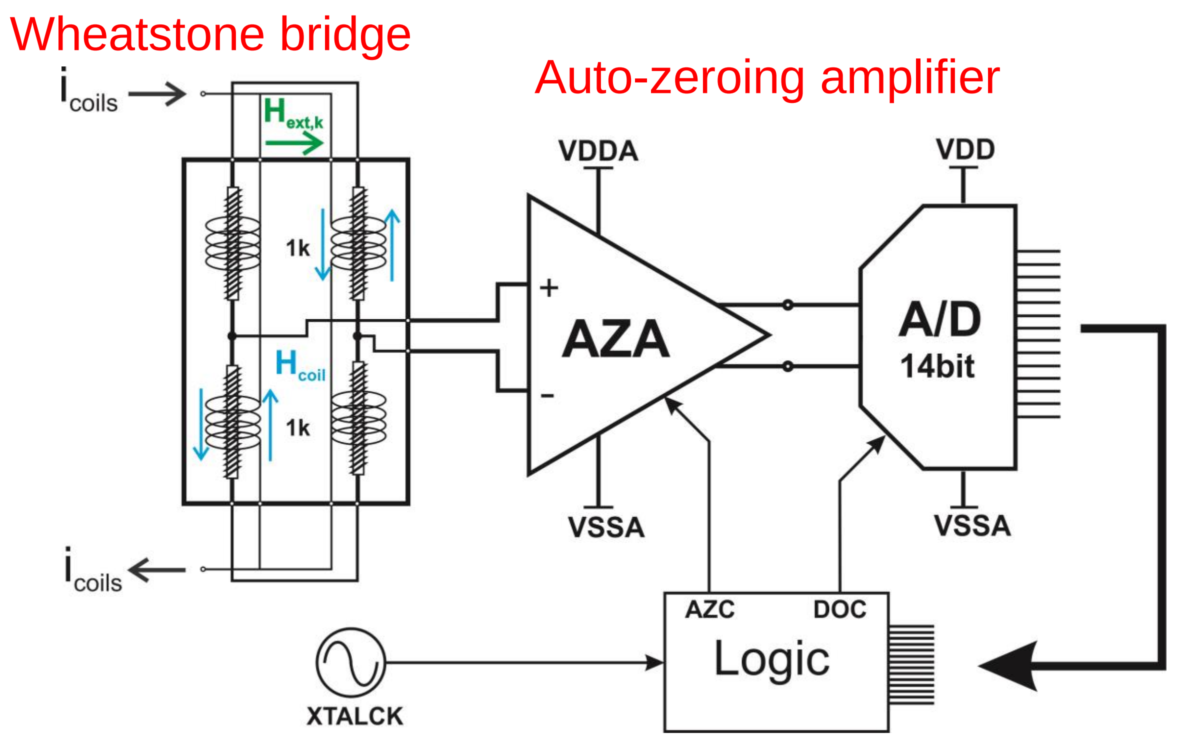
From Tumanski (2001) p.95





L. Gan et al. IEEE Trans on Magnetics (2000)

AMR readout chain



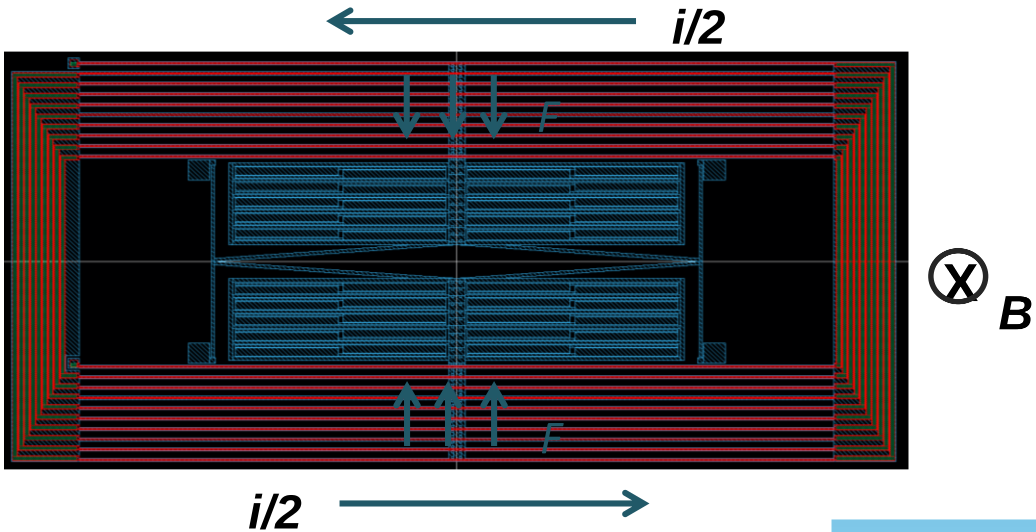
- Switching power mode to mitigate power dissipation
- Amplifier bandwidth of 45kHz

Figure of Merit - Magnetometers

Device	±FSR [µT]	Noise [µT]	Band [Hz]	Current [µA]	FoM [nT·mA/√Hz]
STM LIS3MDL	1.6	0.4	10	90	11.7
Bosch BMM150	1.3	0.3	5	170	22.8
Freescale MAG3110	1.0	0.3	0.75	57	2.0
Asahi Kasei AK8975	1.2	0.3	4	117	17.5
Honeywell HMC5883	0.8	0.2	3.75	33	3.4
AMR	**2.0**	**0.1**	**50**	**145**	**2.0**

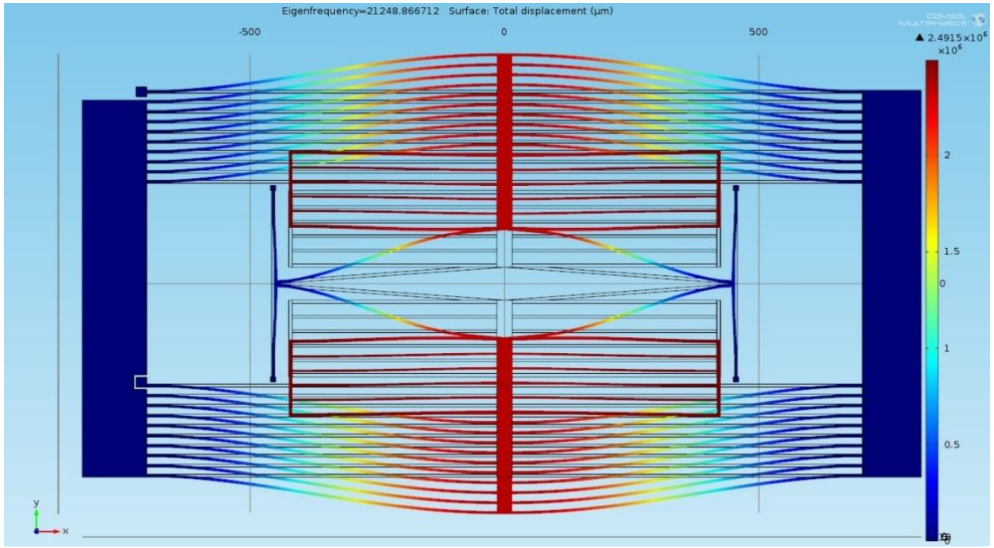
performance per sensing axis

Lorentz Magnetometer

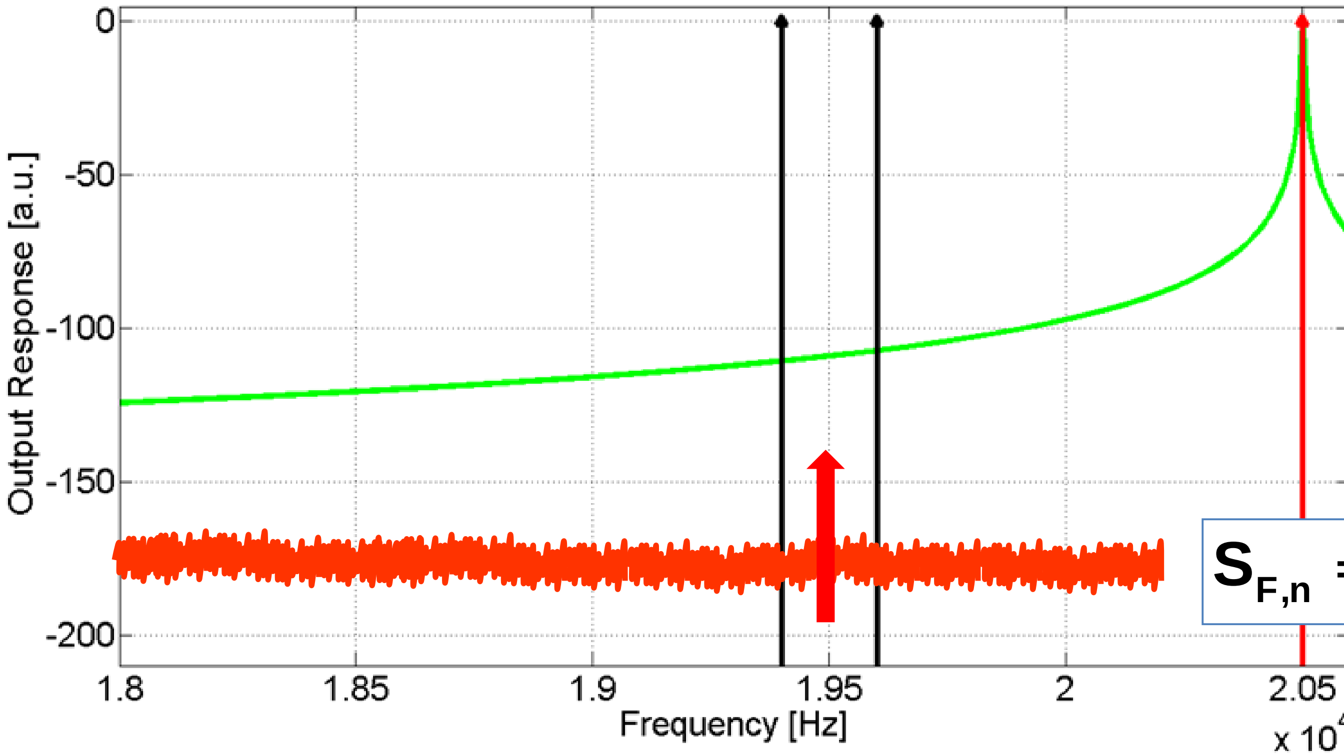


Parallel-plate capacitors are designed inside the device

$$\frac{\Delta C}{C_0} = \alpha \cdot Q \cdot L \cdot i \cdot B_z$$



Lorentz Magnetometer Design

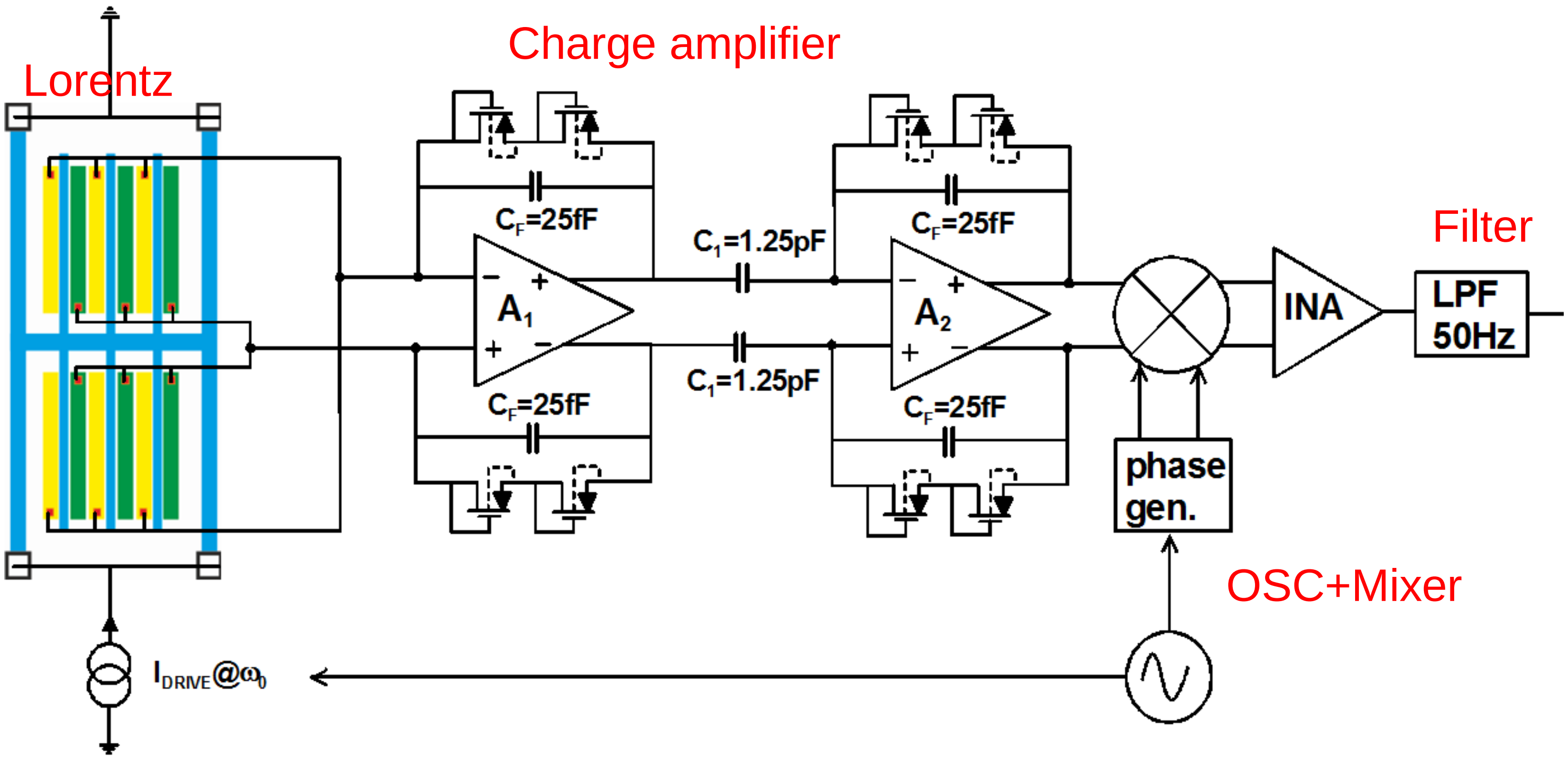


$$S_{F,n} = 4k_bT\ b$$

Off resonance

- **Sensitivity improves by lowering the damping factor - b:**

Lorentz readout chain and drive



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AMR	**2.0**	**0.1**	**50**	**145**	**2.0**
Lorentz	**2.4**	**0.4**	**50**	**135**	**8.0**

performance per axis

Lab4MEMS

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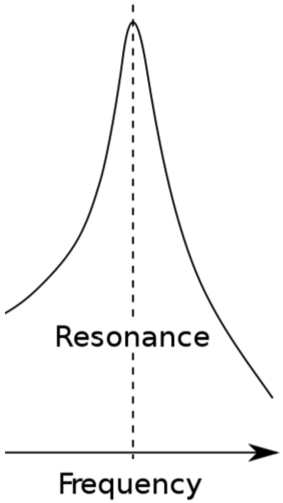
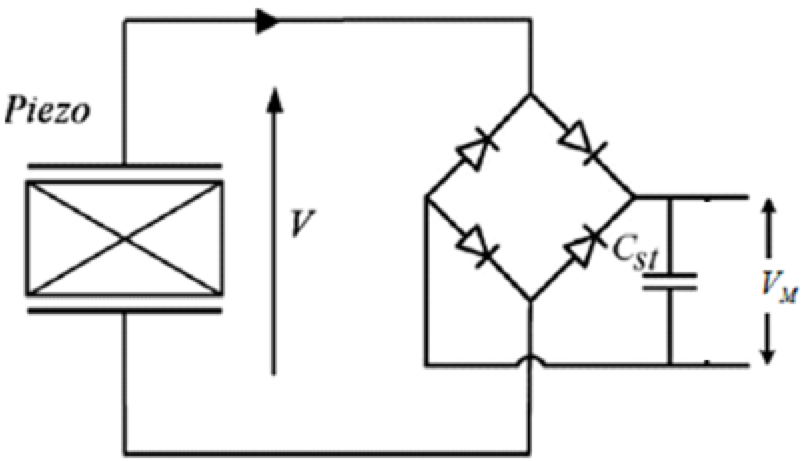
Lorentz type Magnetometer (3 axis)
Photonic Crystal piezo actuator

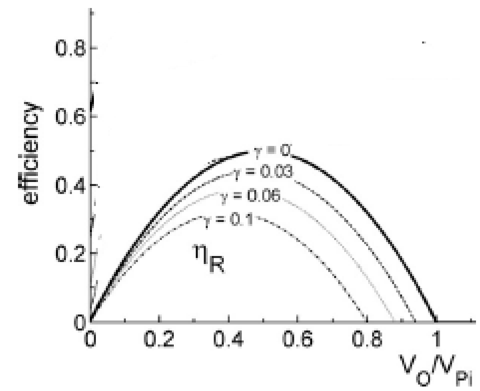
UniBO

piezo power converters

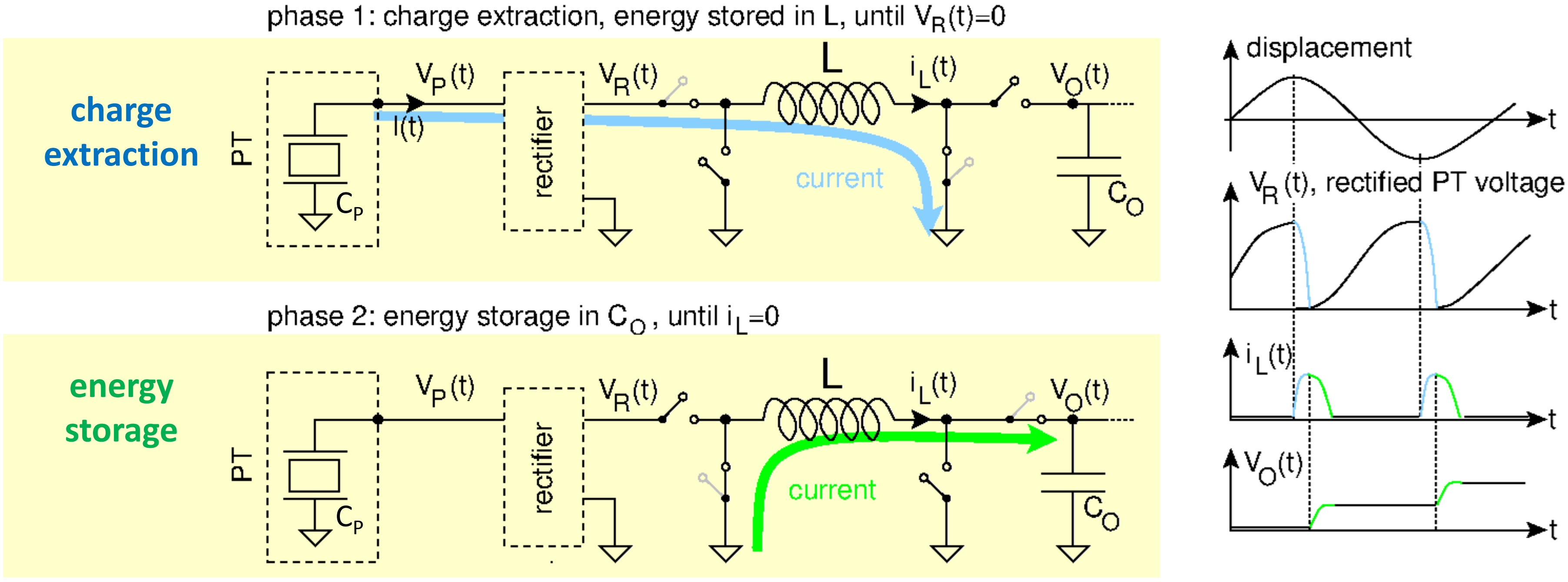




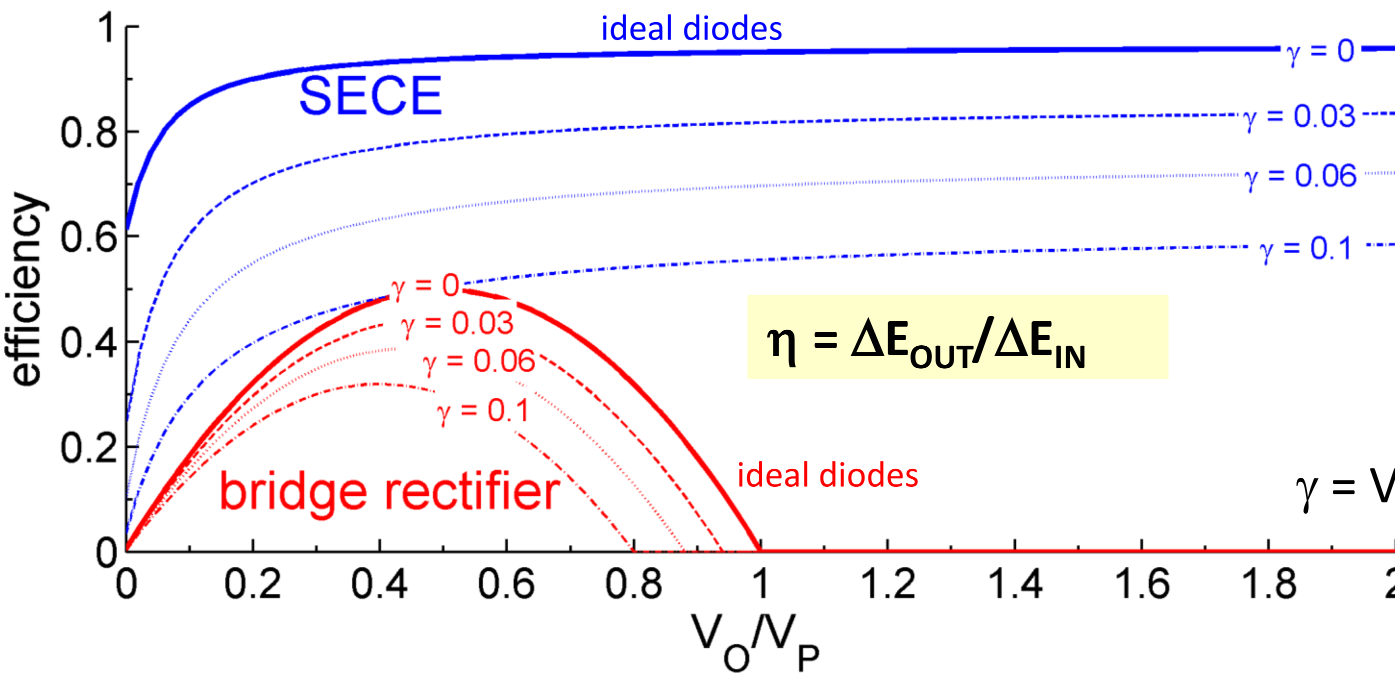
$\eta = \Delta E_{OUT}/\Delta E_{IN}$



Synchronous Electric Charge Extraction



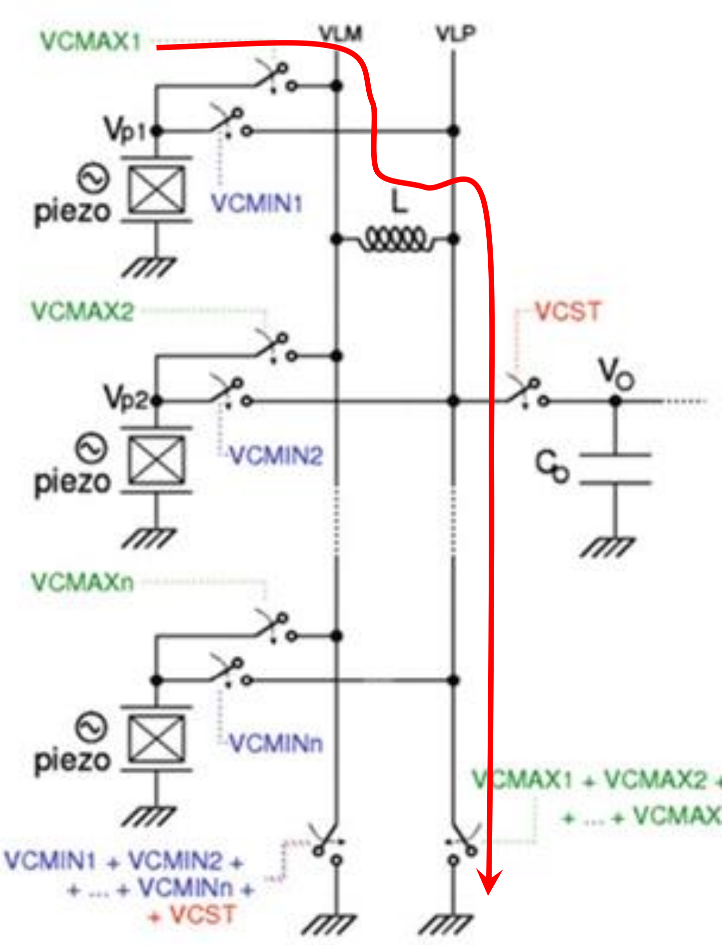
Synchronous Electric Charge Extraction (SECE)

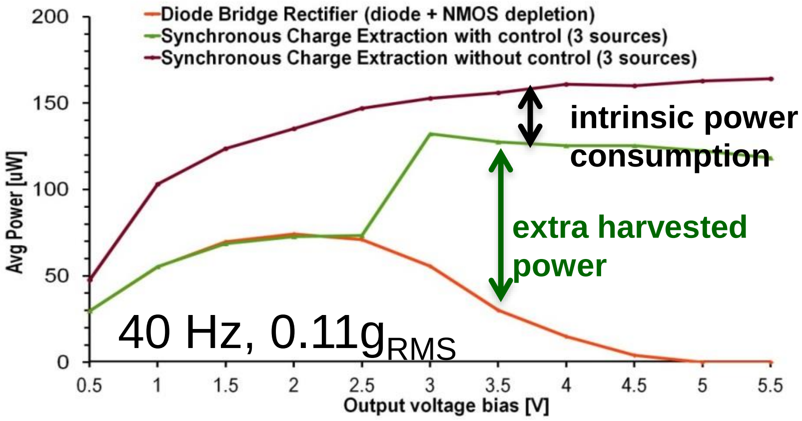


$\eta = \Delta E_{OUT}/\Delta E_{IN}$

$\gamma = V_{TH} / V_P$

Multi source piezo harvester





Performance Comparison with SoA

Work	No. of SRCs	Source Type	Max. input voltage	Power conversion technique	Estimated Current Consumption (@5V supply)	Range of Harvested Power	Self-starting	Technology	Electrical Efficiency
Ramadass, IEEE JSSC 2012	1	Piezo	5 V	SSHI	1 uA	10 – 100 uW	Yes	Integrated	85%
Krihely, IEEE TPEL 2011	1	Piezo	12 V *	SSHI	7 uA	3.96 uW	Yes	Discrete	80%
Elliot, Eurosensors 2012	1	Piezo	n.a.	SSPB	80 uA	3 uW	n.a.	Discrete	n.a.
Kong, IEEE TPEL 2012	1	Piezo	≈10 V	DCM Flyback	20 – 80 uA	8.4 uW	Yes	Discrete	72%
Colomer, IEEE T.Ind.El. 2011	4	Piezo, RF, PV, TEG	2.5 V	Parallel-connected LDOs	30 uA	6.4uW	Yes	Integrated	52-85%
Ferrari, S&A 2008	3	Piezo	n.a.	Parallel-connected passive rectifiers	passive.	32 uW *	Yes	Discrete	n.a.
UNIBO	**3**	**Piezo**	**20V**	**SECE with shared inductor**	**3 – 10 uA**	**300uW**	**Yes**	**Discrete**	**74%**
UNIBO design target	**5**	**Piezo**	**5V**	**SECE with shared inductor**	**< 200 nA**	**5uW – 1 mW**	**Yes**	**Integrated**	**80%**

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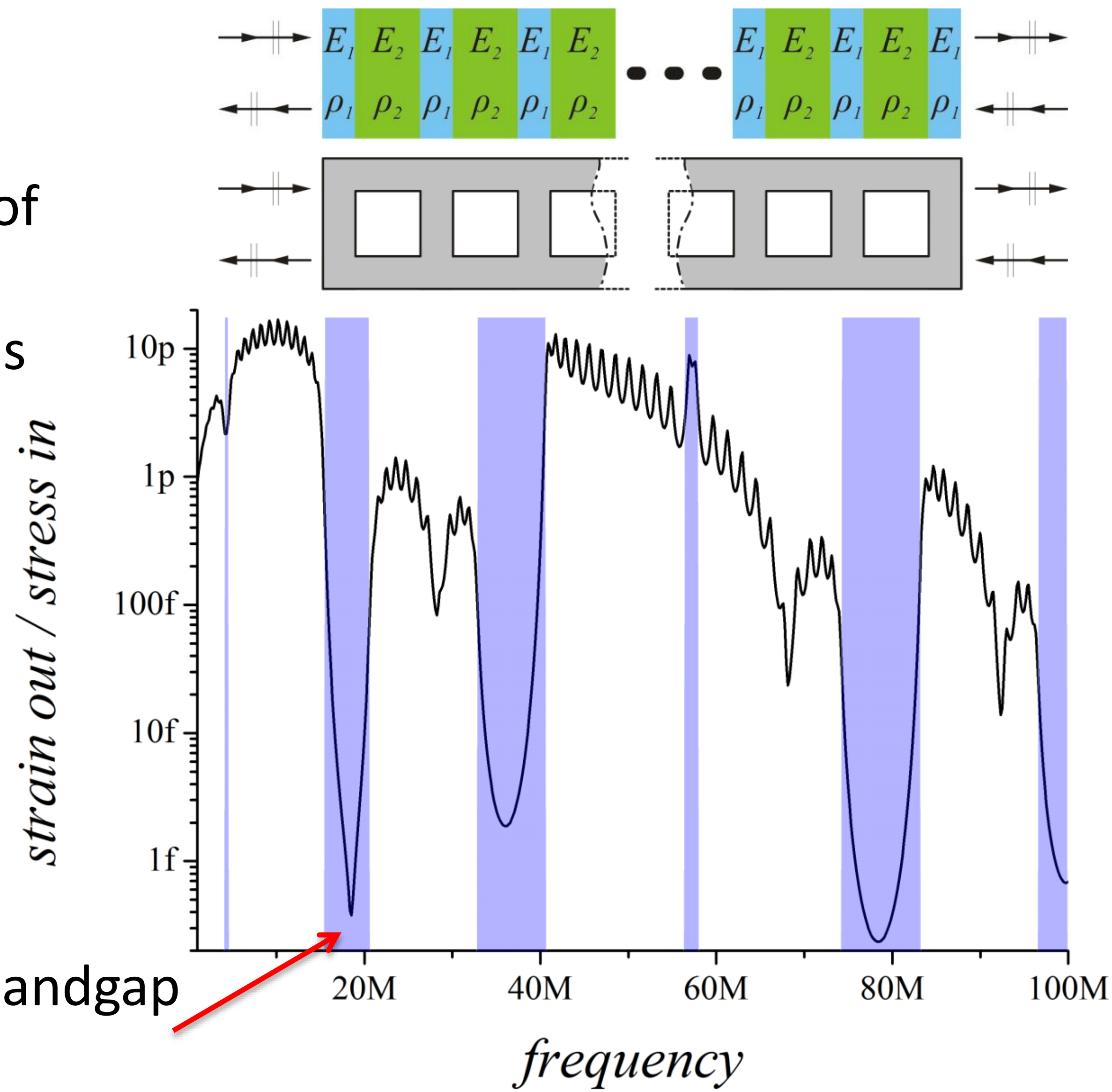
UniPi

Phononic Crystals

1D 2D 3D

Periodic modulation of one or more mechanical properties

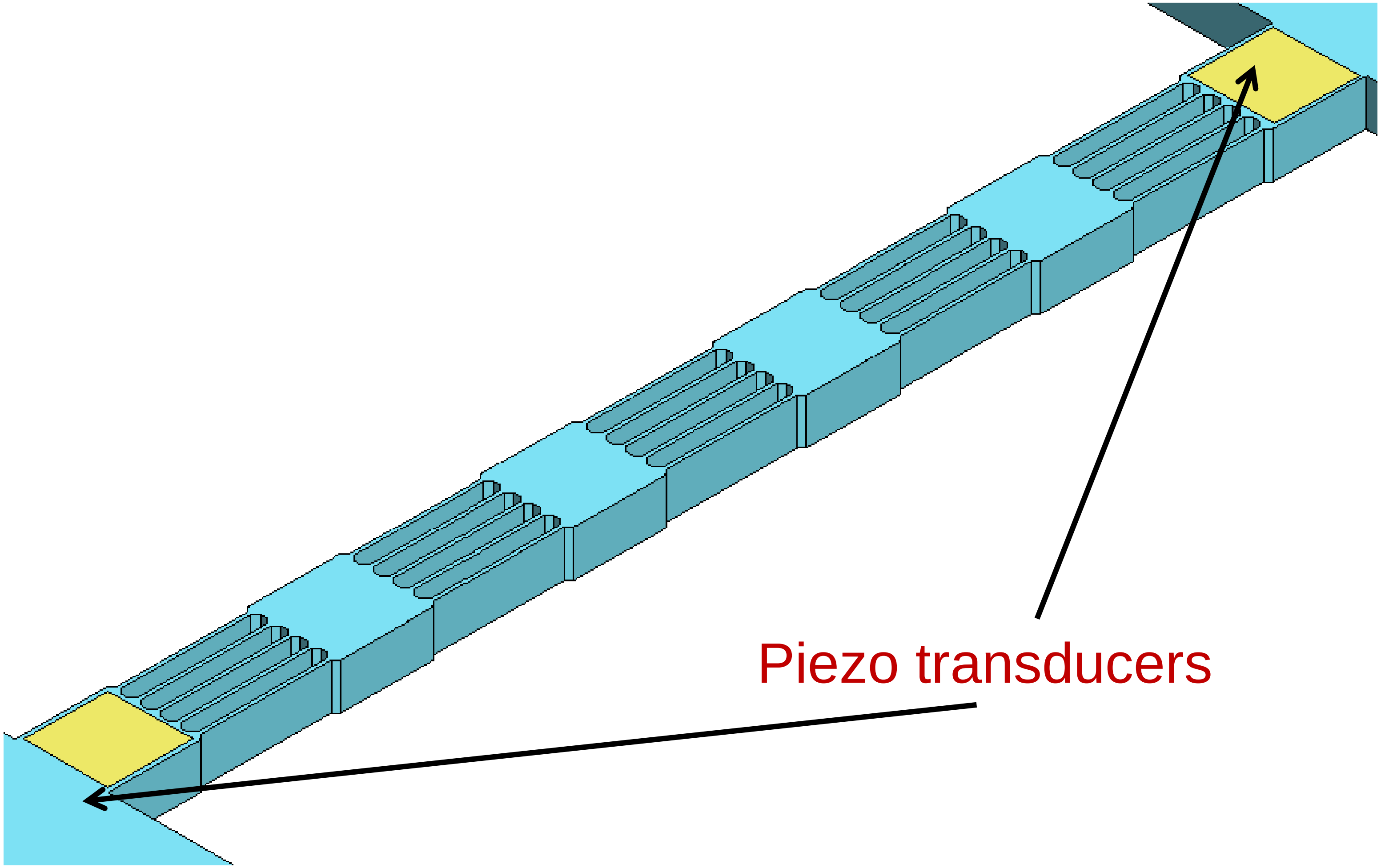
- elasticity
- density
- cross section



phononic bandgap

Resonant mass sensing in Lab4mems

Flexural vibration modes - **piezoelectric actuation and detection**



Resonant mass sensing in Lab4mems

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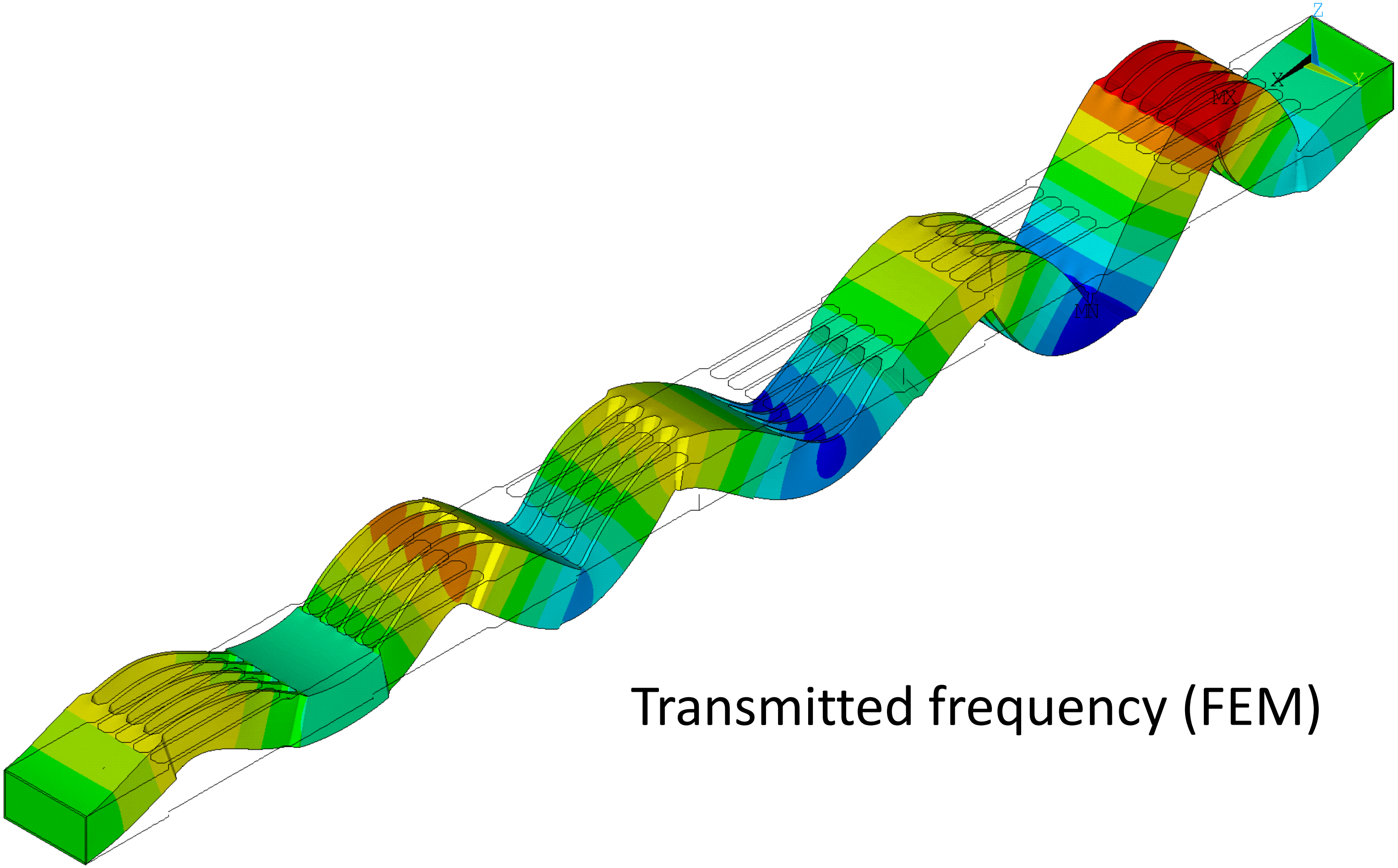
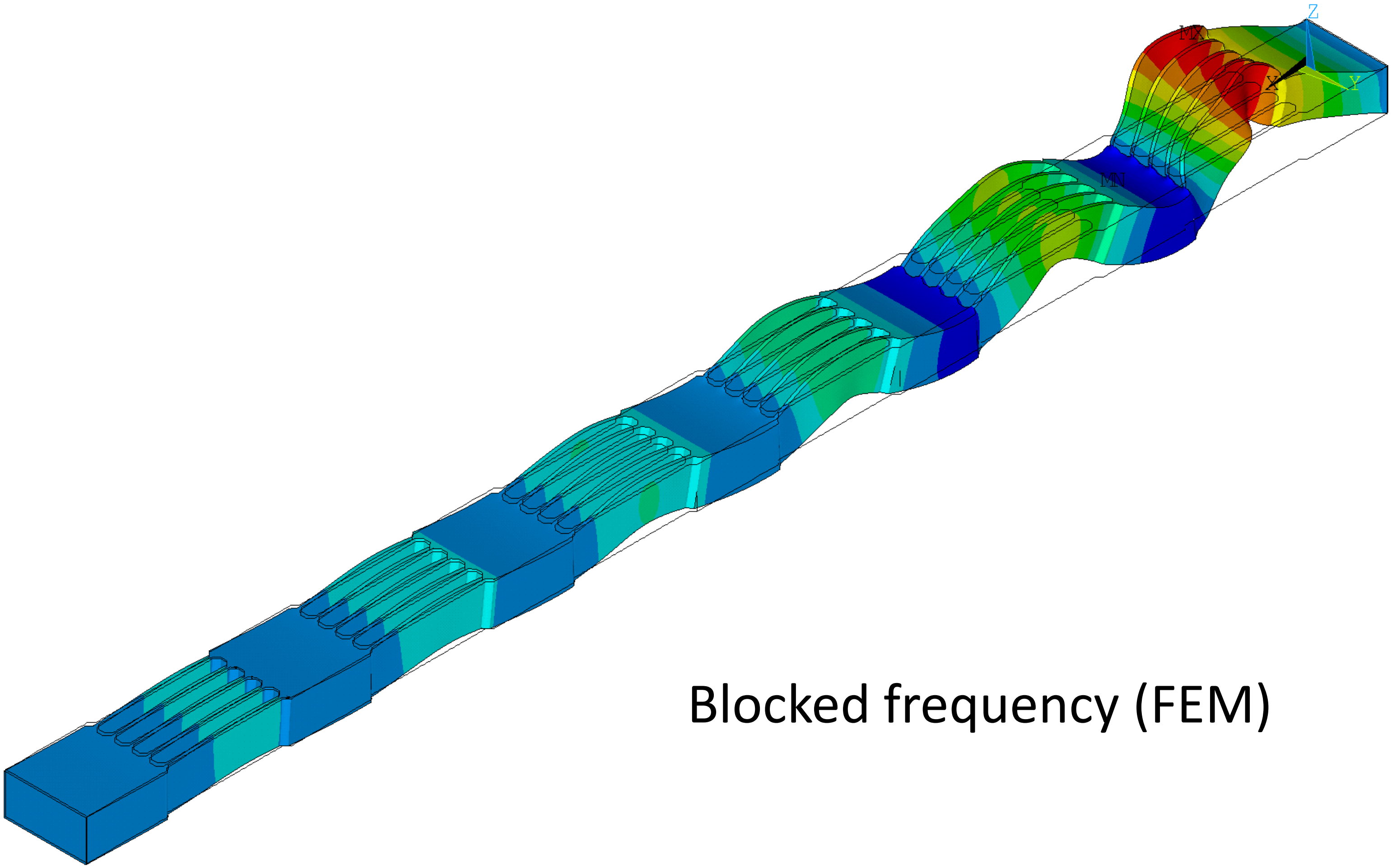


Transmitted frequency (FEM)

Resonant mass sensing in Lab4mems

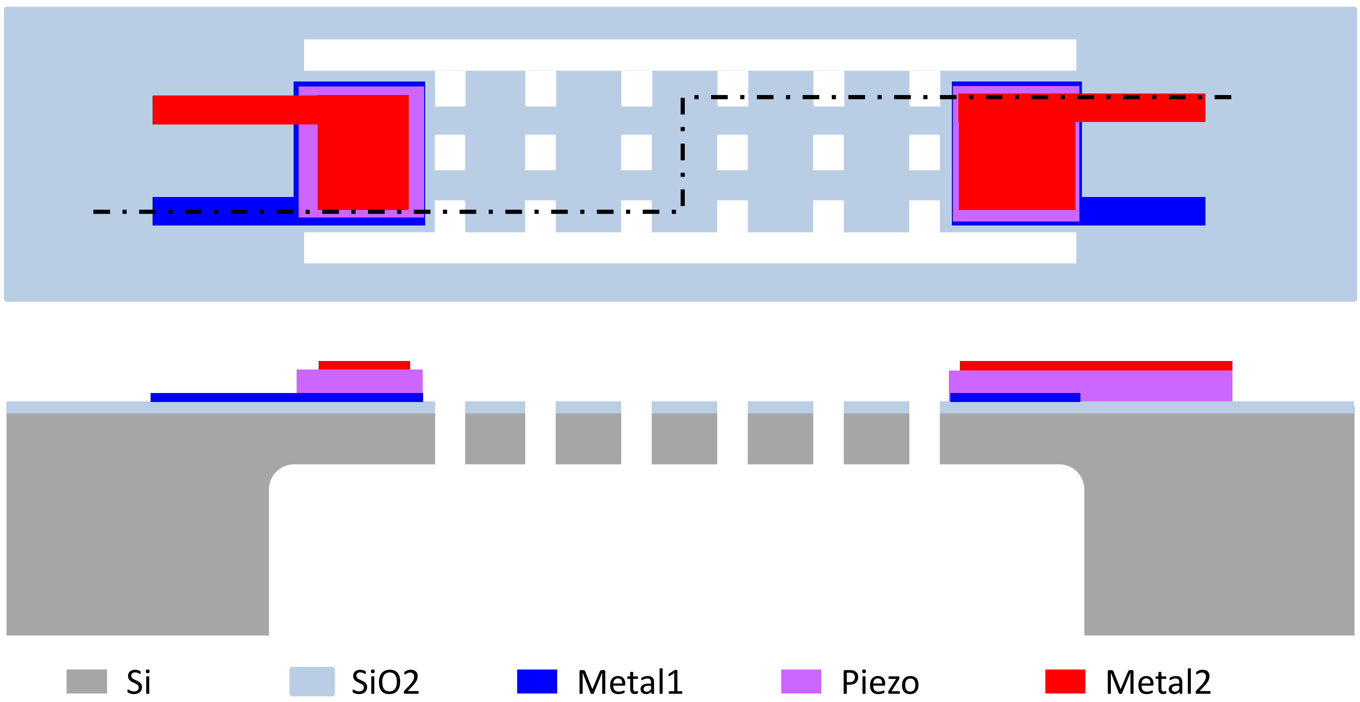
Flexural vibration modes - **piezoelectric actuation and detection**



Blocked frequency (FEM)

Flexural PC design

Five mask process (backside cavity, metal1, piezo, metal2, fronside etch)



Performance Comparison with SoA

Sensor type	Quality factor	Mass/area sensitivity (Hz/Hz)/(kg/m^2)	Operating frequency (MHz)
Quarz Crystal Microbalance (QCM)	>10000 (air)	1	10
Capacitive CMOS	7000 (vac)	1000 (in vac)	3
Surface Acoustic Wave (SAW)	---	60	500
Film bulk acoustic resonators (FBAR)	1100 (air)	30	300
Piezoresistive NEMS	900 (vac)	2600 (in vac)	127
Proposed Ph-C sensor	10000 (vac)	>10 (50)	10

Conclusioni

- H2020 – applicazioni pervasive e clouding
- MEMS – dispositivi e microsistemi
- La Pilot Line italiana e IUNET