



Università degli Studi di Catania
Dottorato di Ricerca in
Ingegneria dei Sistemi,
Energetica, Informatica e delle
Telecomunicazioni
XXXII Ciclo



Development of innovative magnetic field sensors with tuning features for a wide operative range

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Research Theme

The aim of this research topic is based toward the development of integrated magnetic field sensor with a dual application:

- ❖ detection of parking slot occupancy through the sensing of the alterations induced to the local strength of the geomagnetic field due to the presence of metallic targets such as cars or trucks.
- ❖ mapping of the magnetic field dispersed in a particle accelerator.

The detection range is the following:

[1 μ T-2T]

Research Activity

This Ph.D. project is focused on the study and the analysis of a new magnetic field sensor prototype in terms of:

- Definition of the **design** and the **MEMS technology** to be adopted
- Realization of the new **prototype**
- Analysis of the **conditioning circuit** to process the output signal
- **Validation**

[$1\mu\text{T}$ - 2T]



The Lorentz force magnetometer: Working Principle

The working principle is based on the interaction between an unknown external magnetic field to be evaluated and a known current that is generated into a meander cantilever. The amplitude of Lorentz force is correlated them through the following expression:

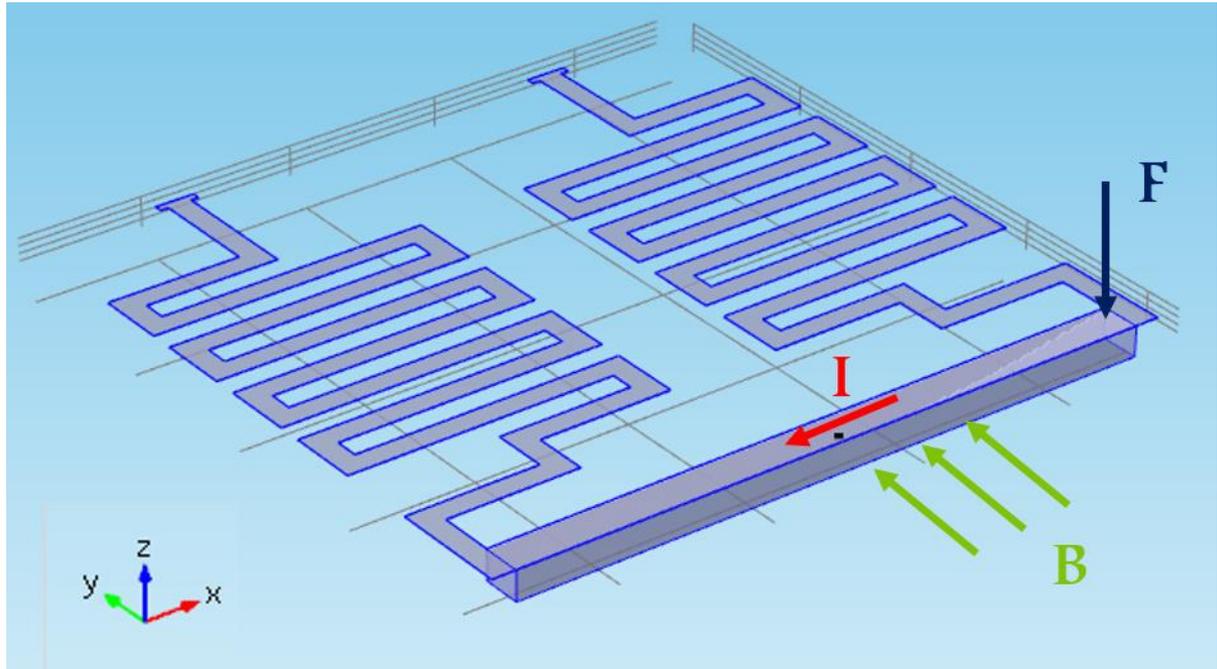


Fig. 1: Schematic

$$F = I \cdot B \cdot L$$

where L is the length of cantilever subjected to perpendicular B.

MEMS Technology: PiezoMUMPs

Among other MEMS fabrication technologies, I have considered PiezoMUMPs technology as the most promising one. An AlN (Aluminum Nitride) piezoelectric layer is used to generate an electric output: this aspect represents the most important advantage in this process.

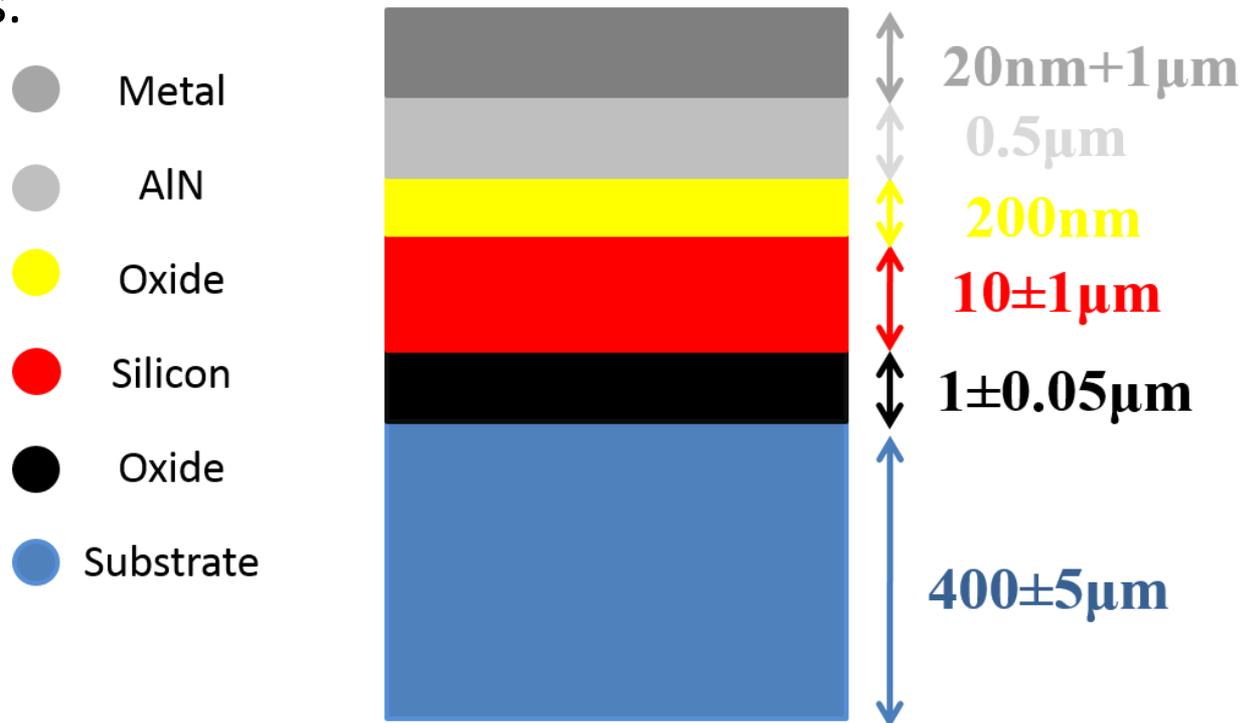
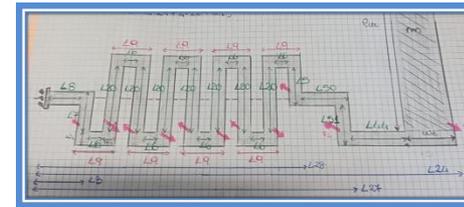
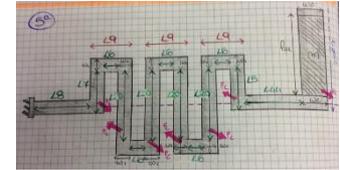


Fig.2: PiezoMUMPs Technology

Description of Flow chart

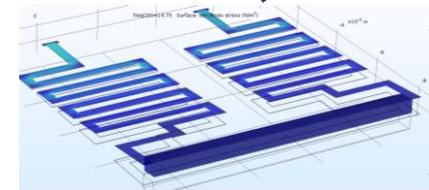
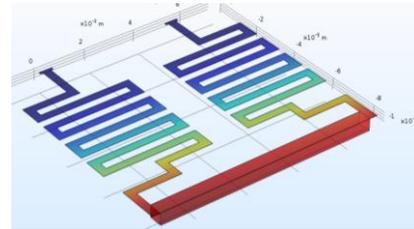
❖ Model analysis in Matlab-Simulink

Different topologies of the U-shaped beam cantilever have been considered in order to investigate static and dynamic model and to evaluate the displacement.



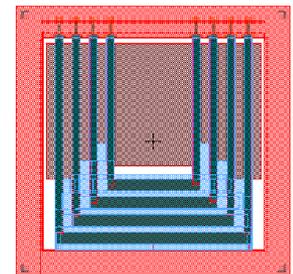
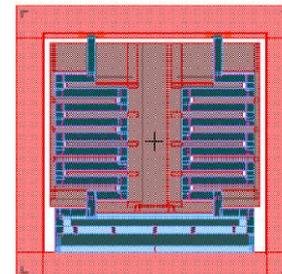
❖ FEM analysis in Comsol Multiphysics

A FEM analysis has been mandatory to estimate deformation and residual stress.



❖ Layout through the MEMSPRO CAD

Two layouts have been realized to have to different readout strategies: piezoelectric and capacitive.



Characterization as Accelerometer

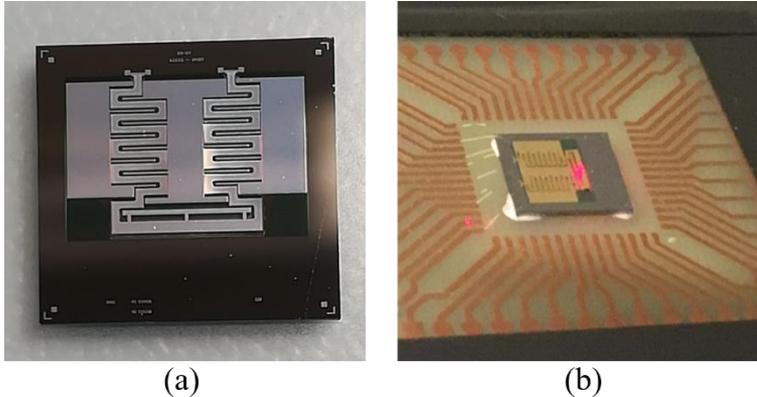


Fig.3: (a) Die; (b) Packaging and bonding

In order to characterize the MEMS accelerometer the die has been packaged and bonded on a PCB board (Fig. 3b) and afterwards an appropriate experimental setup has been realized in Fig. 4a.

The fabrication of the device has been pursued with MEMSCAP and the die is shown in Fig. 3a.

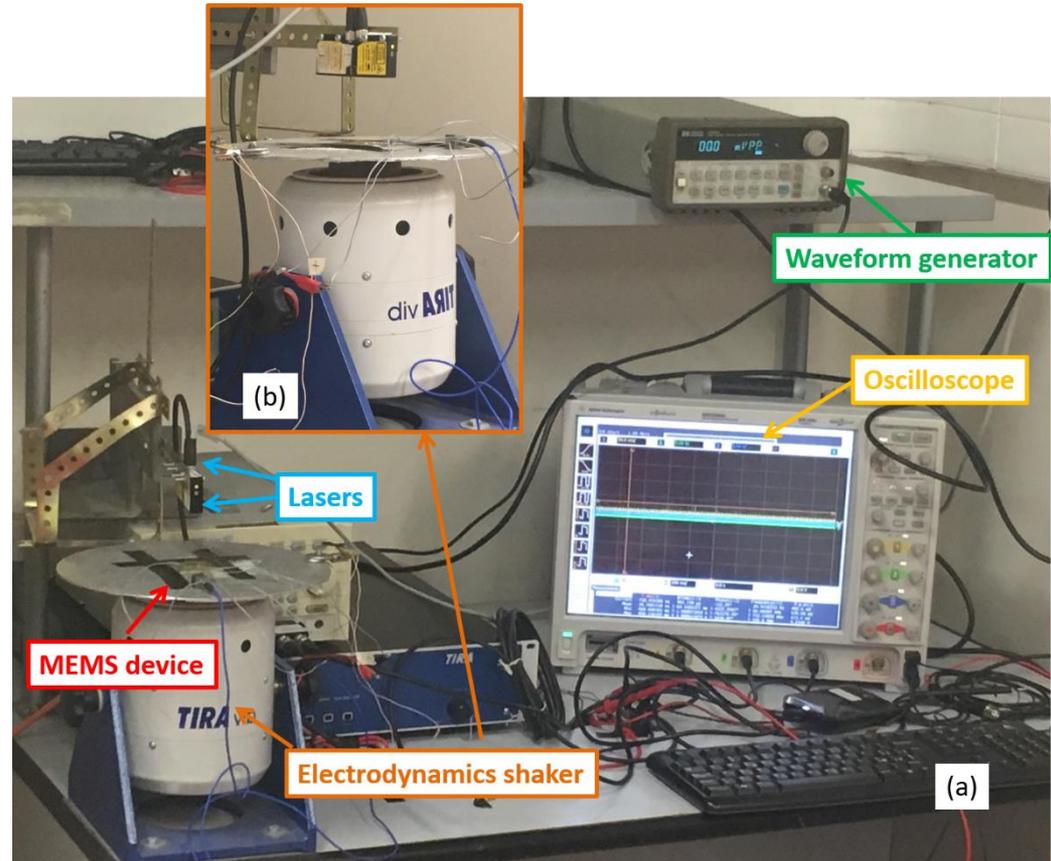


Fig.4: Experimental setup for mechanical characterization

Characterization as Accelerometer : Results

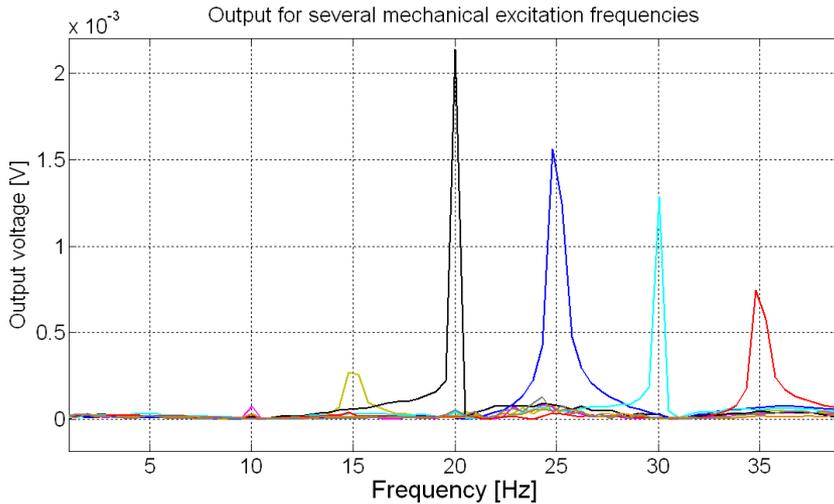


Fig.5: Evaluation of the resonance frequency.

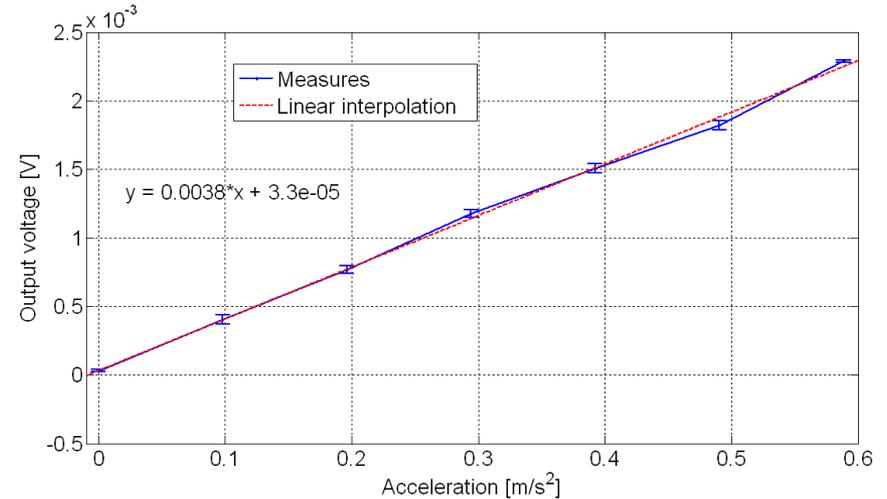


Fig.6: Piezoelectric output as a function of the external acceleration.

A resonance frequency of **~20 Hz**, a sensitivity of **~0.0038 V/(m/s²)**, a noise level of **~3.37e-05 V** and a resolution of **~0.0089 m/s²** have been experimentally estimated.

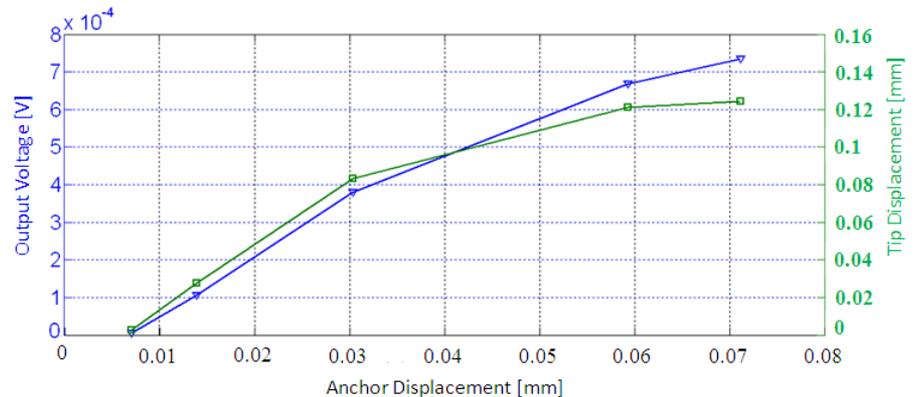


Fig.7: Correspondence between tip displacement and output voltage as a function of anchor displacement.

Research activity at



A period of 5 months has been spent at CERN, in Geneva, in order to characterize the MEMS device as magnetic field sensor. The measurements have been implemented in the *Batiment 311* of MM (*Magnetic Measurements*) group.



Fig.10: Reception

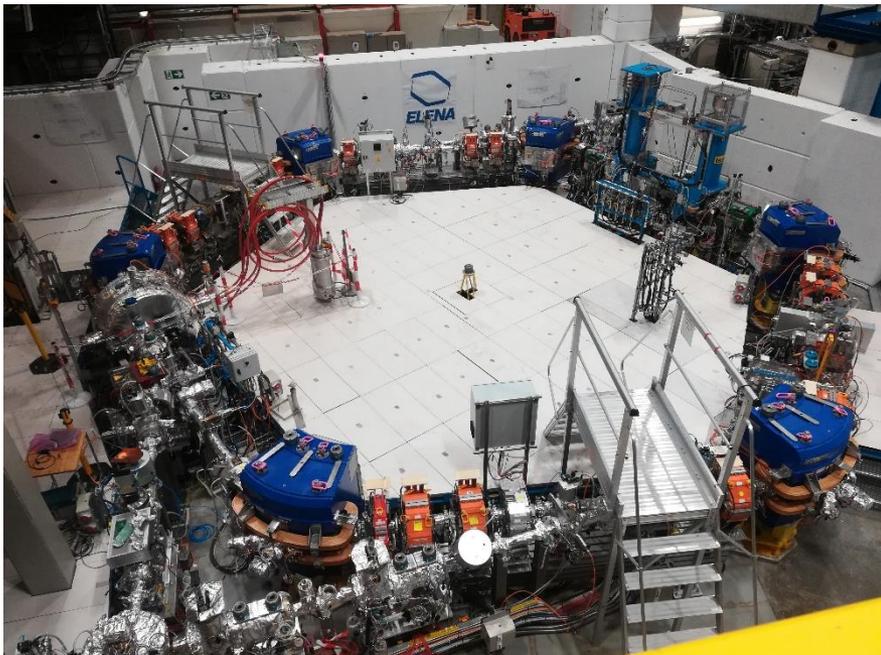


Fig.11: ELENA Experiment



Fig.12: Normal Conductive Magnets

Research activity at



In order to actuate the MEMS device through the Lorentz force and to characterize it as magnetic field sensor a suitable experimental setup has been carried out in the *Batiment 311* of *MM group*, at CERN.

The experimental setup is composed of the following instruments:

- a **normal conductive dipole**, able to create an uniform magnetic field until 0.8 T (nominally)
- **KEITHLEY 6221 DC AND AC CURRENT SOURCE** to drive the current into MEMS device
- **PROJEKT ELEKTRONIC GmbH BERLIN** (Teslameter) used to monitor the DC magnetic field into the dipole

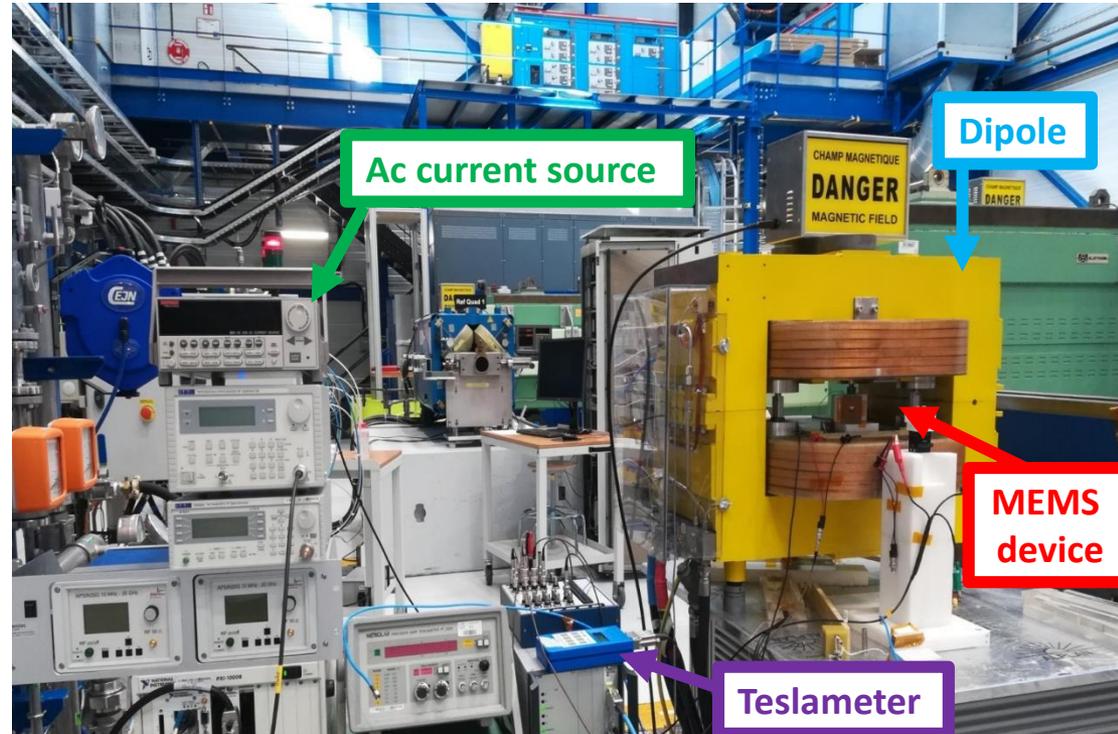
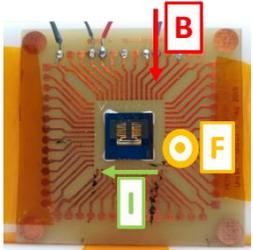


Fig.13: Experimental Setup at CERN.

- **DAQ NI usb-6366** to acquire the input, the magnetic field and the output voltage
- a **power converter** used to provide current to the magnet and the relation between current and magnetic field is:

$$0.877165 \text{ mT/A}$$

Research activity at



The output voltage has been obtained applying a constant magnetic field in the range [0-25] mT and a sinusoidal current having a frequency of 20 Hz (that is the resonance frequency) and an amplitude of 10 mA and 40 mA.

Piezo Output Voltage

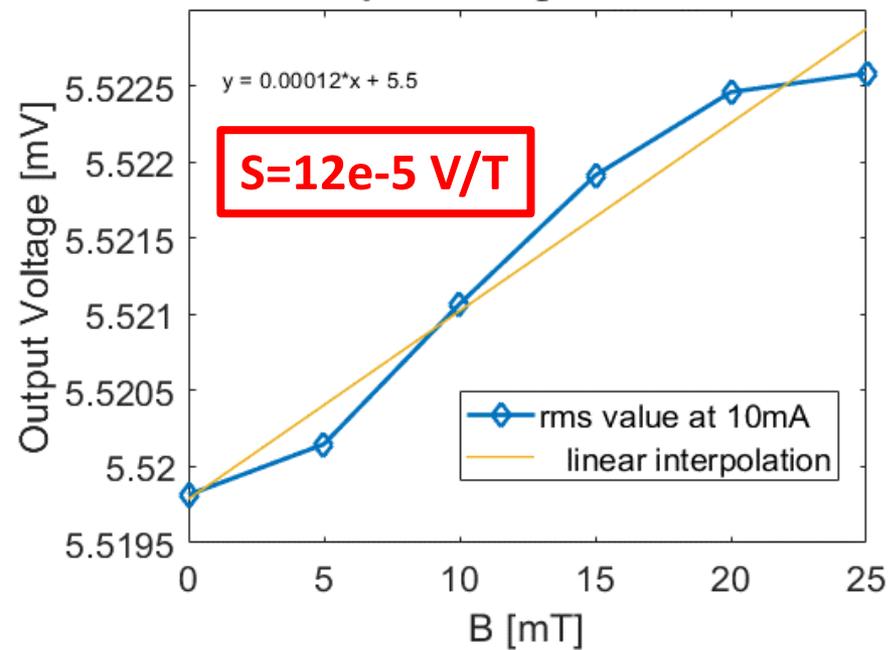


Fig.14: Output voltage VS magnetic field at 10 mA

Piezo Output Voltage

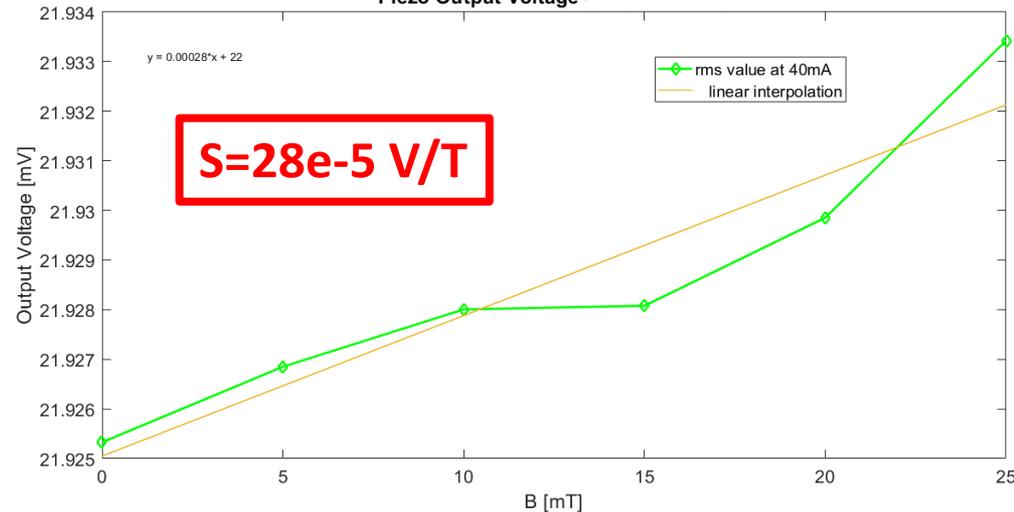


Fig.15: Output voltage VS magnetic field at 40 mA

Layout through the MEMSPro CAD

Other two layouts have been implemented using the MEMSPro CAD. The differential configuration has been selected to amplify the output voltage and this approach is indicated for the application in Paradox, where a weak variation of geomagnetic field is produced by the presence of a car.

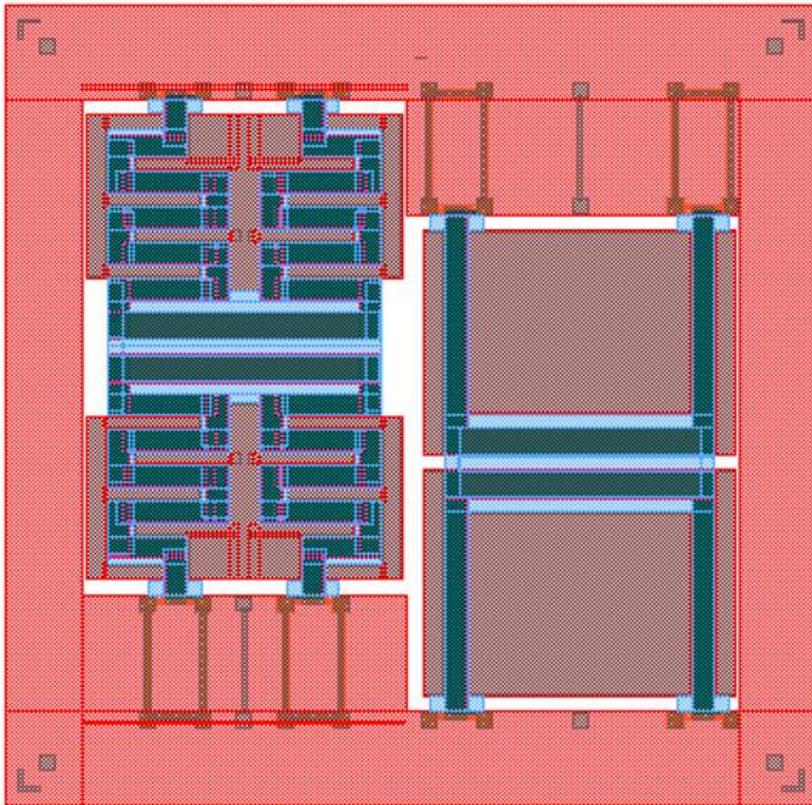


Fig.16: Differential Architecture

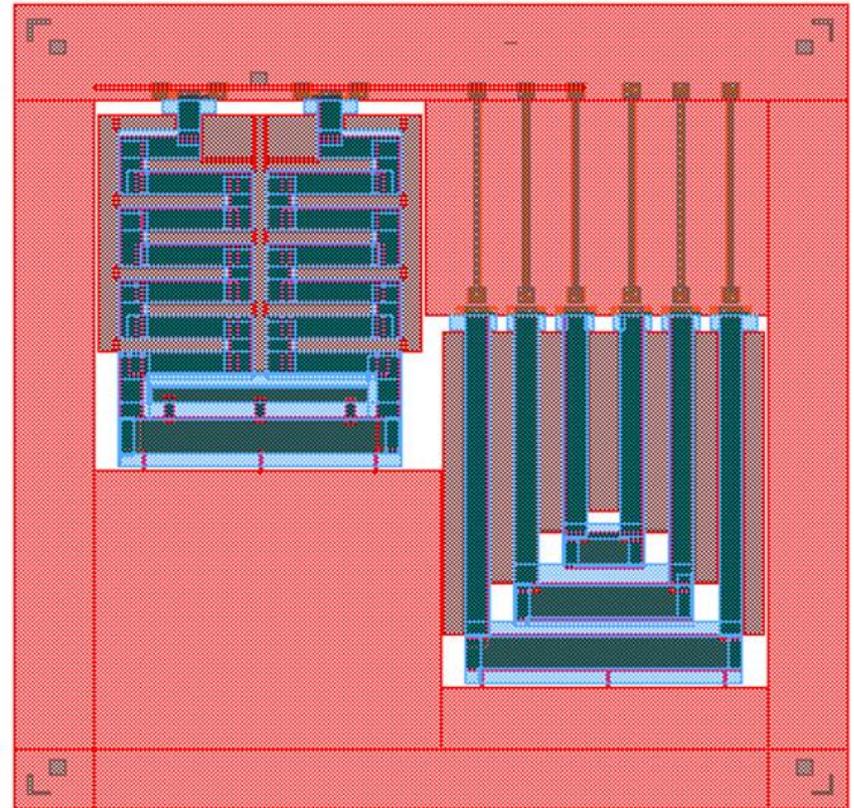


Fig.17: Reduced structure

Further Activities

At the moment the research activity is engaged in :

- the study and the simulation of circuit conditioning for both readout strategies (piezoelectric and capacitive readout)
- Simulations in Comsol Multiphysics of new architectures

Following steps will be focused on :

- Characterization of new MEMS devices
- Preparation for sensors applications
 - Testing phase at Paradox Engineering, Novazzano, Switzerland, in order to detect the presence or absence of a car in a parking slot (“smart cities” application).

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2. C. Trigona, B. Andò, V. Sinatra, C. Vacirca, E. Rossino, L. Palermo, S. Kurukunda and S. Baglio, *“Implementation and Characterization of a Smart Parking System based on 3-axis Magnetic Sensors”*, I2MTC 2016.
3. C. Trigona, V. Sinatra, B. Andò, S. Baglio and A.R. Bulsara, *“ Flexible Microwire Residence Times Difference Fluxgate Magnetometer”*, IEEE TIM, 66, Issue 3, pp. 559–568, 2017.
4. A. Beninato, V. Sinatra, G. Tosto, M. Castagna, S.Petralia, S. Conoci, and S. Baglio, *“Inductive integrated biosensor with extended operative range for detection of magnetic beads for magnetic immunoassay”*, IEEE TIM, 66, Issue 2, pp. 348–359, 2017.
5. M.E. Castagna, S. Petralia, A. Beninato, V. Sinatra, S. Baglio and S. Conoci, *“ Magnetic Beads Compatibility as DNA Hybridization Labels in Integrated Thermal-Magnetic Biosensor ”*, BionanoScience 2017, pp.1-7.
6. C. Trigona, V. Sinatra, B. Andò, S. Baglio, A.R. Bulsara, G. Mostile, M. Zappia and A. Nicoletti, *“RTD-Fluxgate Sensor for Measurement of Metal Compounds in Neurodegeneratives Diseases”*, I2MTC, Turin 22-25 2017.
7. C. Trigona, V. Sinatra, B. Andò, S. Baglio, A.R. Bulsara, G. Mostile, M. Zappia and A. Nicoletti, *“Measurements of Iron Compound Contentin the Brain,using a Flexible Core Fluxgate Magnetometer at Room Temperature”*, IEEE TIM, vol. 67, no 4, pp. 971 – 980, April 2018.

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8. C. Trigona, V. Sinatra, B. Andò, S. Baglio, G. Mostile, A. Nicoletti, M. Zappia and A.R. Bulsara, *"Fluxgate magnetometers for measuring iron compound concentration in human brain: preliminary results"*, CNS Conference, Catania, February 21-23, 2018.
9. C. Trigona, V. Sinatra, G. Crea, R. Nania, B. Andò and S. Baglio, *"PiezoMUMPs Microsensor for Contactless Measurements of DC Electrical Current"*, I2MTC, Houston, Texas, USA 14-17 May 2018.
10. V. Marletta, R. Crispino, V. Sinatra, D. Mascali, A. Mazzaglia, S. Baglio, B. Andò and S. Graziani, *"A FluxGate based approach for Ion Beam current measurement in Electron Cyclotron Resonance Ion sources beamline"*, I2MTC, Houston, Texas, USA 14-17 May 2018.
11. V. Marletta, R. Crispino, V. Sinatra, G. Torrisi, A. Mazzaglia, S. Baglio, B. Andò and S. Graziani, *"A FluxGate-based approach for Ion Beam current measurement in ECRIS beamline: design and preliminary investigations"*, Proceeding of I2MTC 2018 (accepted on TIM).
12. C. Trigona, V. Sinatra, G. Crea, B. Andò and S. Baglio, *"Characterization of a PiezoMUMPs Microsensor for Contactless Measurements of DC Electrical Current"*, IEEE TIM (in press).
13. C. Trigona, V. Sinatra, B. Andò, S. Baglio, G. Mostile, A. Nicoletti, M. Zappia and A. R. Bulsara, *"Fluxgate magnetometer and performance for measuring iron compounds"*, Lecture Notes in Electrical Engineering, Proceed. of the 4° National Conf. on Sensors, chapter 61, Catania, Italy, 21-23 Febr. 2018.

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16. V. Sinatra, C. Trigona, A. R. Fallico, S. Puglisi, B. Andò, and Salvatore Baglio, *“Scanning RTD-Fluxgate as biomimetic artificial whisker”*, Proceeding on I2MTC 2019 (submitted on Special Issue I2MTC 2019).
17. C. Trigona, V. Sinatra, B. Andò, S. Baglio and A.R. Bulsara, *“Exploring the possibility of using RTD-Fluxgate Magnetometers for the detection of brain iron accumulation”*, I&M Magazine (accepted).

Thank you for your kind attention !!!