Business from technology

SGEM – Magnetometer background

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Magnetometer history in brief

- VTT (Technical Research Centre of Finland) has developed MEMS magnetometers since 2003
- The magnetometers are designed to be used as electronic compass in navigation applications and power measurement
- We can deliver wafer level vacuum packaged MEMS chips for tests
- The advantages of VTT magnetometer manufacturing technology are
  - Robust process (does not involve processing of magnetic materials)
  - CMOS compatible, can be integrated with ASIC or other MEMS sensors
  - Infrequent need for recalibration, no creep
- Publications:
  - 1) 3D Micromechanical compass, J. Kyynäräinen et al., Sensor Letters 5, no. 1, p. 126-9 (2007)
  - 2) A 3D micromechanical compass, J. Kyynäräinen et al., Sensors & Actuators A 142, p. 561-8 (2008)

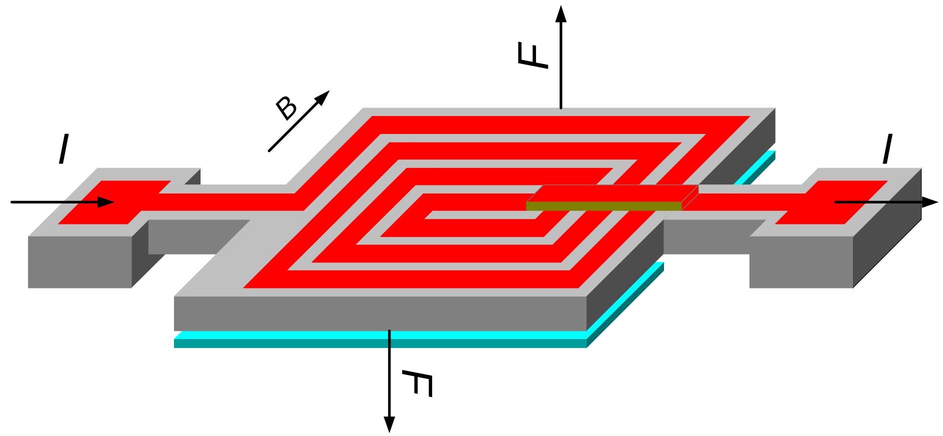
Principle of operation

- Based on the Lorentz force *F :*

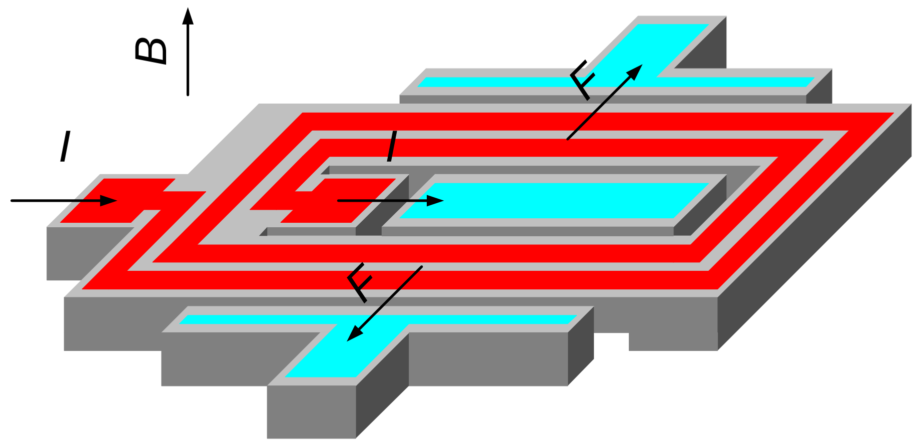
$$\vec{F}_L = I\vec{L} \times \vec{B}$$

- Multi-turn coil processed on a silicon resonator, Coil length *L*
- Coil current I_{AC} = 100 µA
- Magnetic flux density *B*
- Resonating sensor: Q-value enhancement of oscillation amplitude, *f*res = 8…50 kHz
- Capacitive readout for low noise and power consumption

"seesaw" for B_x and B_y:



"detf" (double-ended tuning fork) for B_z:



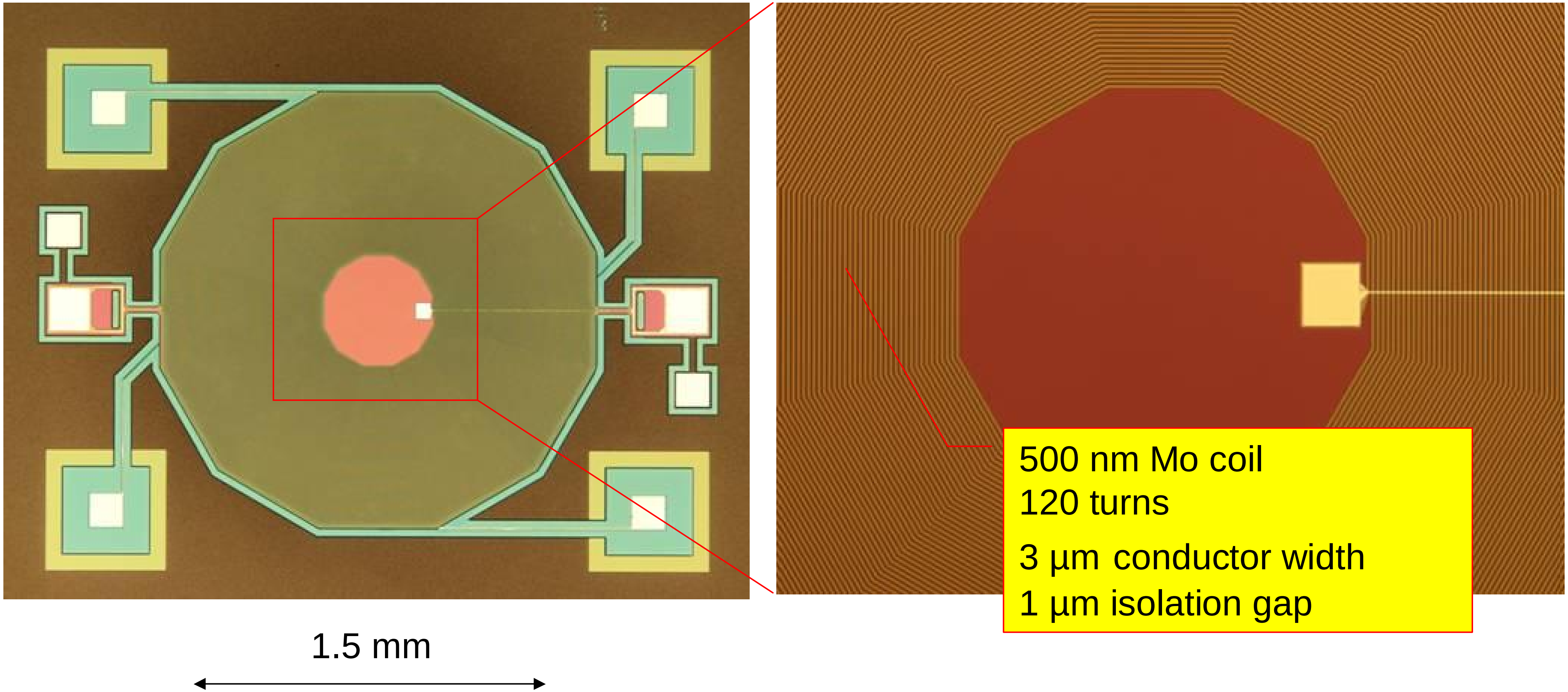
Resonating MEMS magnetometer

- Fundamental resolution limited by thermo-mechanical noise:

$$f_{n,m} = \sqrt{\frac{4k_B T \omega_{res} m}{Q}} \qquad B_{\min} = \frac{f_{n,m}}{\left| I\vec{L} \times \vec{u}_B \right|}$$

- Electronics noise usually less significant when using capacitive readout
- Single crystal silicon resonator: good stability expected
- Vacuum encapsulation required to reach high Q values

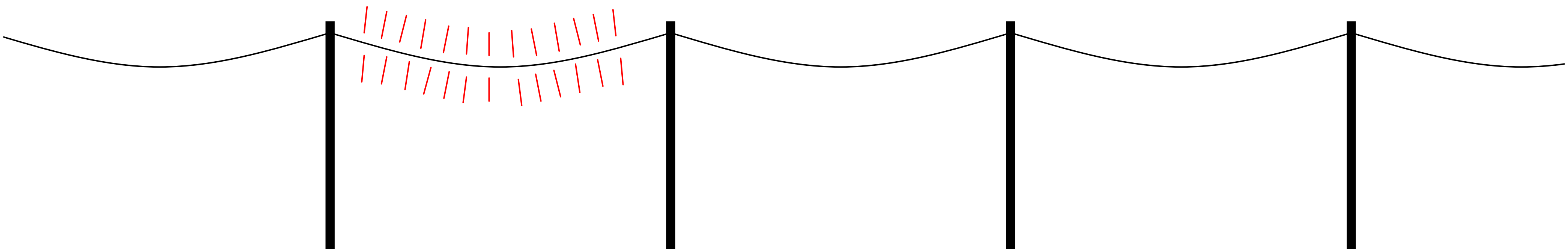
Examples of seesaw sensors



Sensor dimension : 4 x 2 x 1.2 mm

Magnetometer in power measurement

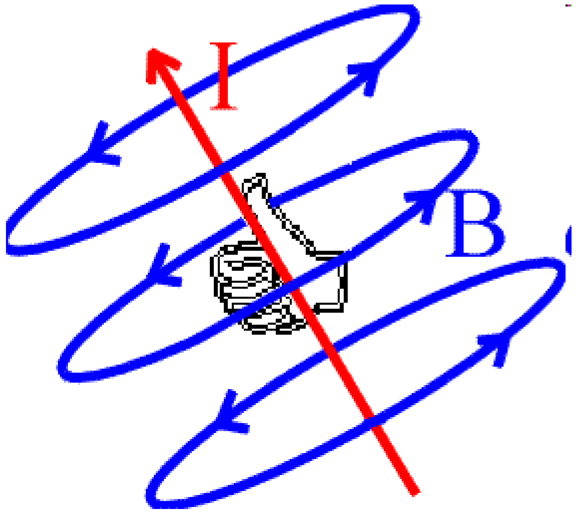
- With SGEM, VTT aims at developing sensors for power measurement
- Power lines create low power magnetic fields proportional to the electrical current
- With a magnetometer correctly placed, we can measure the magnetic field and determine the electrical current on the line



- This measure can be used to evaluate the load of the power line and to detect faults (broken wire or ground short)

High power measurement

- The magnetometer measurement range is in the order of 100 µT
- At 10 cm, measures up to 50 A
- At 1 meter, up to 500 A
- The resolution of the measurement is 1%FS at 500 Hz and can be increased with proper averaging

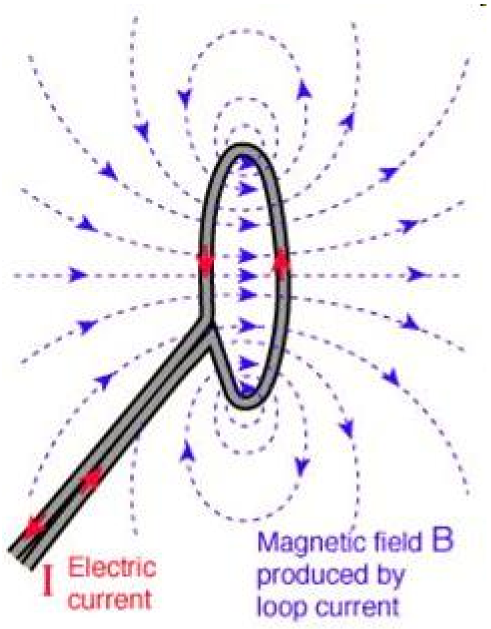


$$B = \frac{\mu_0 I}{2\pi r}$$

Low power measurement

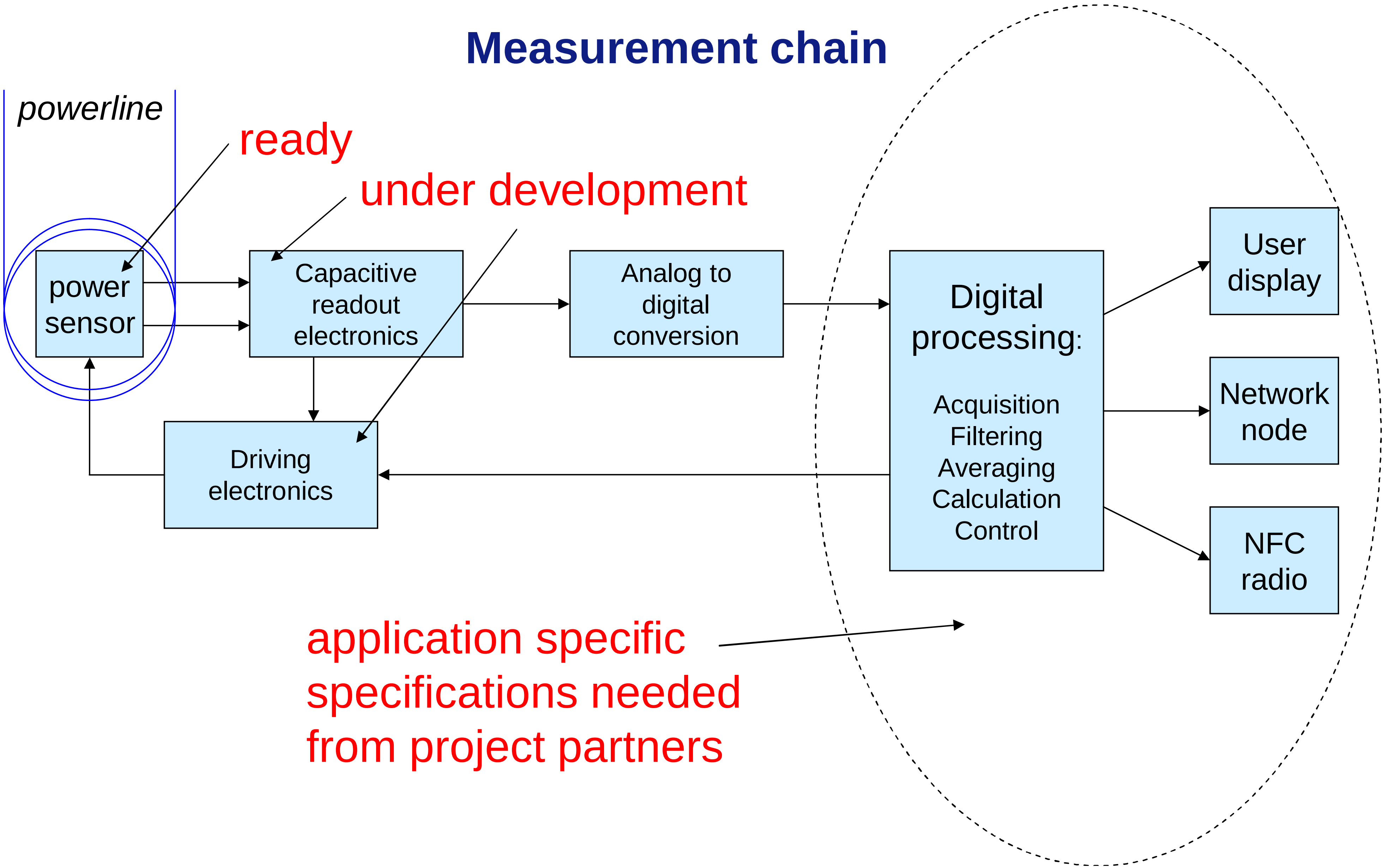
- The magnetometer sensor can also be used for smaller power measurement, for ex household equipments or even for the electrical meter

- With a loop of the mains cable (or a few loops) we can measure several amperes.



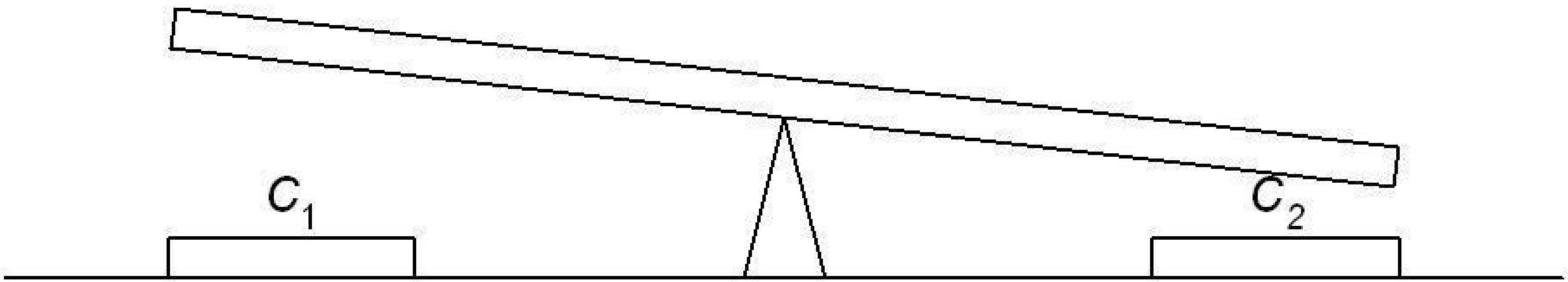
$$B = \frac{\mu_0 \, N \, I}{h}$$

Measurement chain



Capacitive readout principle

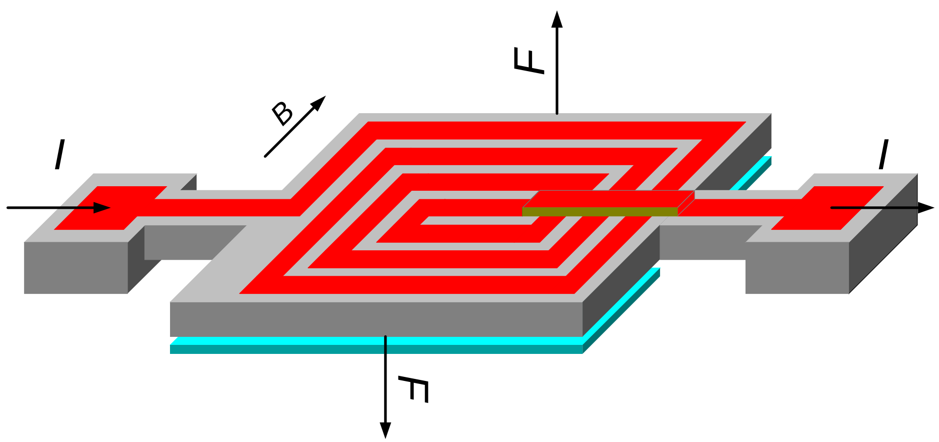
- The moving plate is set to vibrate at it's natural mechanical resonance frequency by external excitation current (voltage)
- The property to be measured is the amplitude of changes in the capacitance



- Tilt of the plate determines the capacitance C1 and C2 (approximated to be parallel plate capacitors)
- Tilt and thereby the capacitance is fluctuating at a 8…50 kHz rate
- External magnetic field increases the amplitude

Characteristics of Capacitive Readout

- Capacitance to be measured is around 1 pF, with changes of 10%
- Sway of the moving plate is obtained by an excitation current through a coil in the resonating plate (frequency 8…50 kHz)



Challenges in capacitive readout

- Tiny mechanical structure causes stray capacitances
  - ”Excitation current” easily couples to the readout
- Readout methods charge the plate electrodes
  - Electrostatic forces affect the mechanical resonance
- Problems caused by the resonating plate and the excitation current set high demands for the readout electronics
  - In accelerometers etc. the measured capacitance is static and there is no interfering bias current
  - Also the excitation current supply needs some sophisticated electronics

Different readout methods

- Reading the plate electrodes
  - RC-timing circuit
    - Good SNR for long distances
  - Wheatstone bridge and other adapted impedance measurements
    - Several different designs,
    - Numerous ready circuits
    - Easily affects the resonance
  - Phase difference measurements
    - Some designs need an external coil
    - Standard circuits made for different frequencies

- Readout could also be implemented by causing the oscillation with the electrodes and measuring the coil voltage

- RC timing circuit was chosen because it seems to cause least stress on normal operation and resulting frequency modulated signal might be beneficial in some applications

Conclusions

- Magnetometer MEMS chips have been fabricated in an other project
- Measurements have proved that the magnetometer works in the micro Tesla area
- Readout is still carried out mainly with laboratory instruments
- Designing a compact, simple and error free way to read the magnetometer is still in progress
- Simple readout technology will make the magnetometer cheap and easy to apply in consumer electronics and still offer the best resolution

VTT creates business from technology