Session III – parte A

Sensori e relativi sistemi di sviluppo

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System LAB

STMicroelectronics

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TALENTIS

Prerequisiti:

Libreria firmware per i sensori MEMS

http://www.st.com/content/st_com/en/products/embedded-software/mcus-embedded-software/stm32-embedded-software/stm32cube-expansion-packages/x-cube-mems1.html

Libreria per Bluetooth

http://www.st.com/content/st_com/en/products/embedded-software/mcus-embedded-software/stm32-embedded-software/stm32cube-expansion-packages/x-cube-ble1.html

Function Pack STM32 ODE per Internet of Thing

http://www.st.com/content/st_com/en/products/embedded-software/mcus-embedded-software/stm32-embedded-software/stm32-ode-function-pack-sw/fp-sns-motenv1.html

STM32 ST-LINK utility

http://www.st.com/en/development-tools/stsw-link004.html

Interfaccia PC

http://www.st.com/content/st_com/en/products/embedded-software/evaluation-tool-software/unicleo-gui.html

App per Smartphone

http://www.st.com/content/st_com/en/products/embedded-software/wireless-connectivity-software/bluems.html

Agenda

Educational part: What is a Sensor? What are the MEMS? Overview of ST Sensors?

Lab: How to connect a Sensor Board on Nucleo? How to acquire Data on PC?

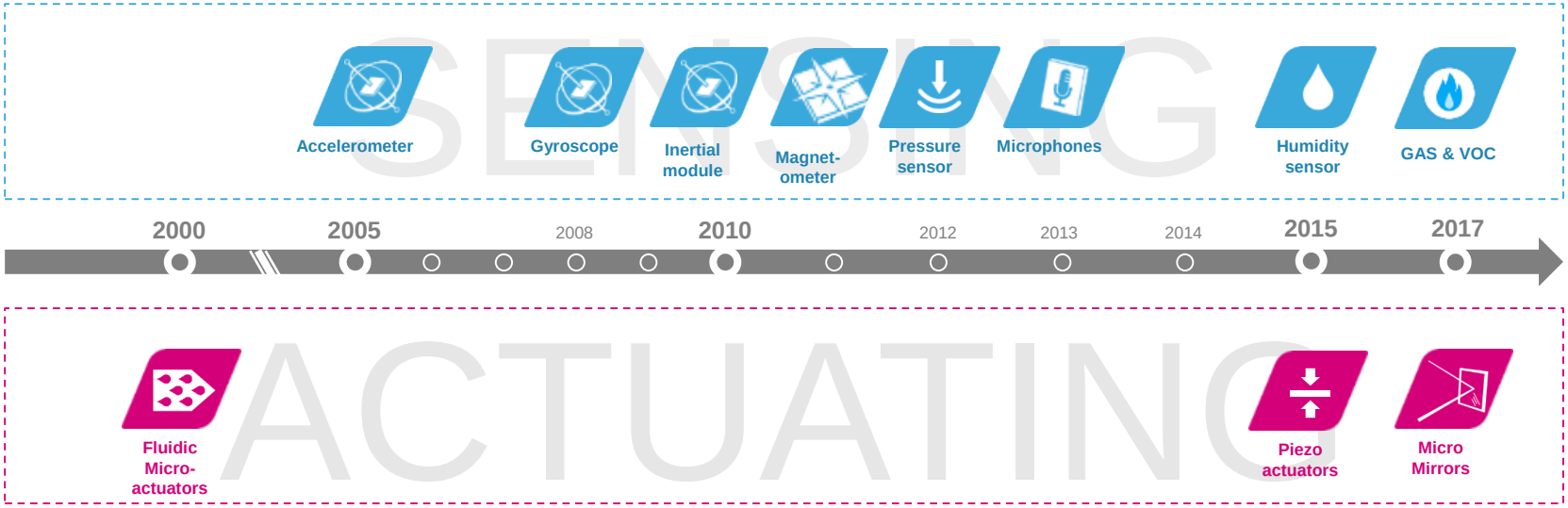
Break

Education part: ST portfolio on Connectivity. What is a Bluetooth Low Energy?

Lab: How to connect Bluetooth over the Sensors? How to retrieve data on Smartphone?

20 Years MEMS Sensors & Actuators

ST Innovations



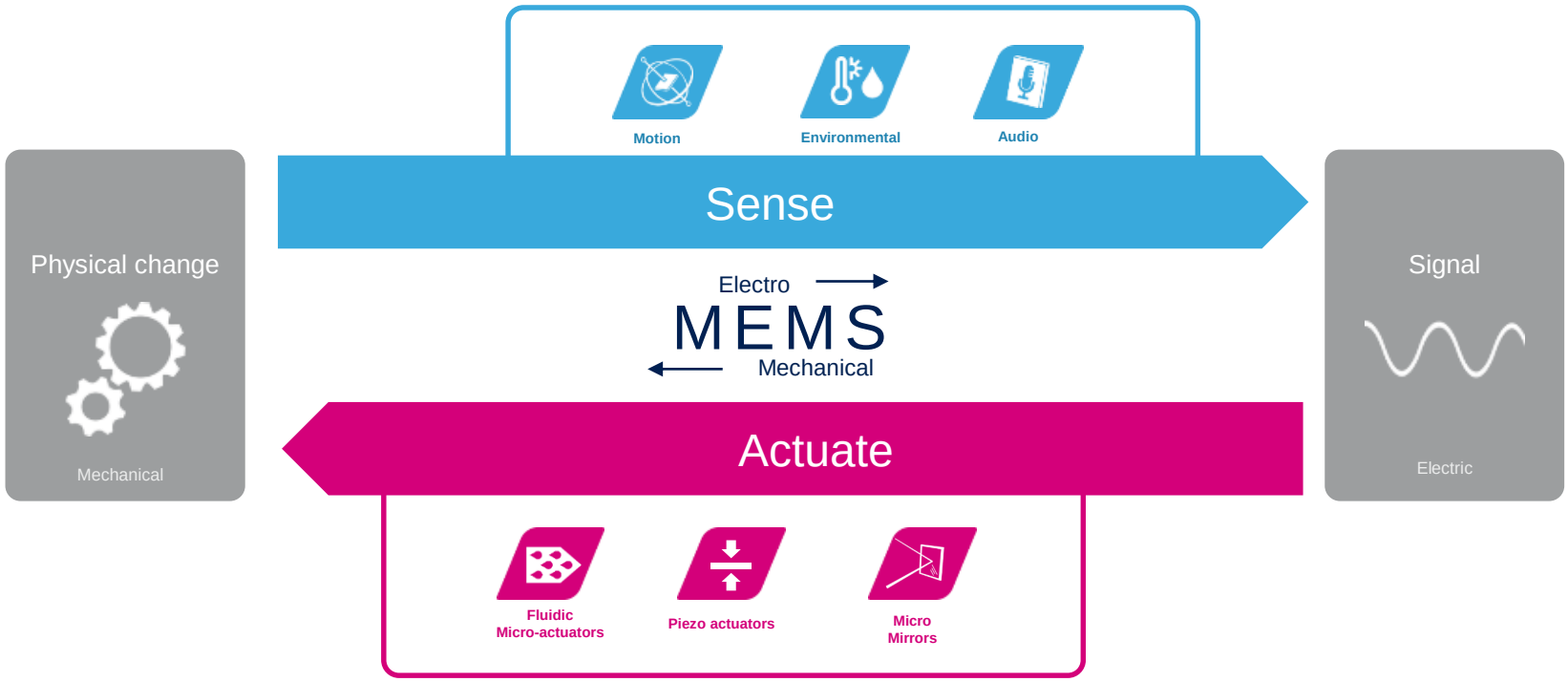
What is a sensor?

A sensor is a **converter** that measures a **physical quantity** and converts it into another one that can be read by an observer or an instruments.

Ideally

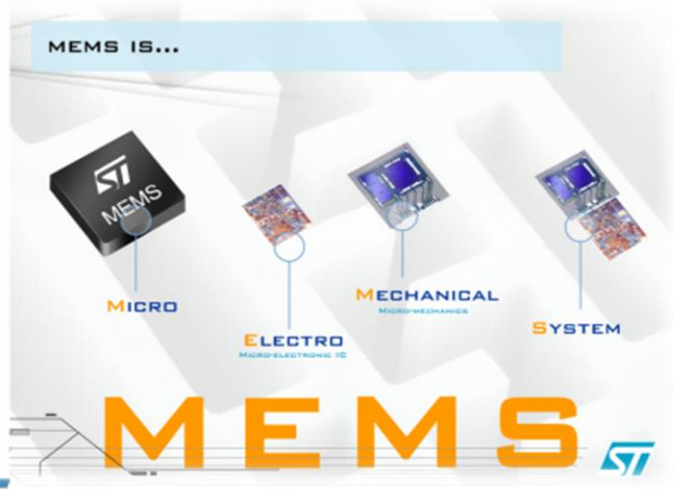
- It is sensitive just to the measured property
- Do not influence the measured property itself
- Its working principle can be described by simple mathematical function
- Using the math function is possible to “traduce” the physical magnitude to measure, in an electrical desired magnitude which will be used in your system.

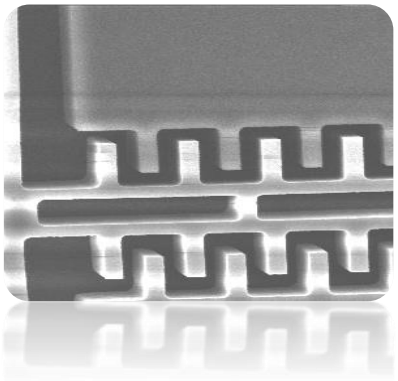
MEMS Sensors & Actuators

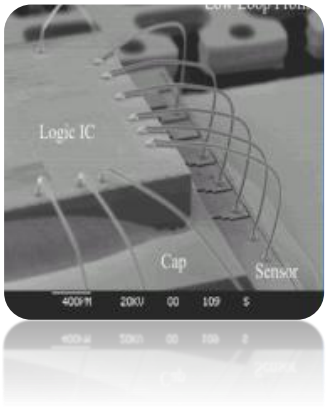


What are MEMS…

- **MEMS** stands for Micro Electro Mechanical Systems
- They contain 3-Dimensional structures realized through a specific process called Micro-Machining
- They are micron-sized devices that interact with the external world for sensing and actuation
- *In MEMS* **not only electrons are moving!**







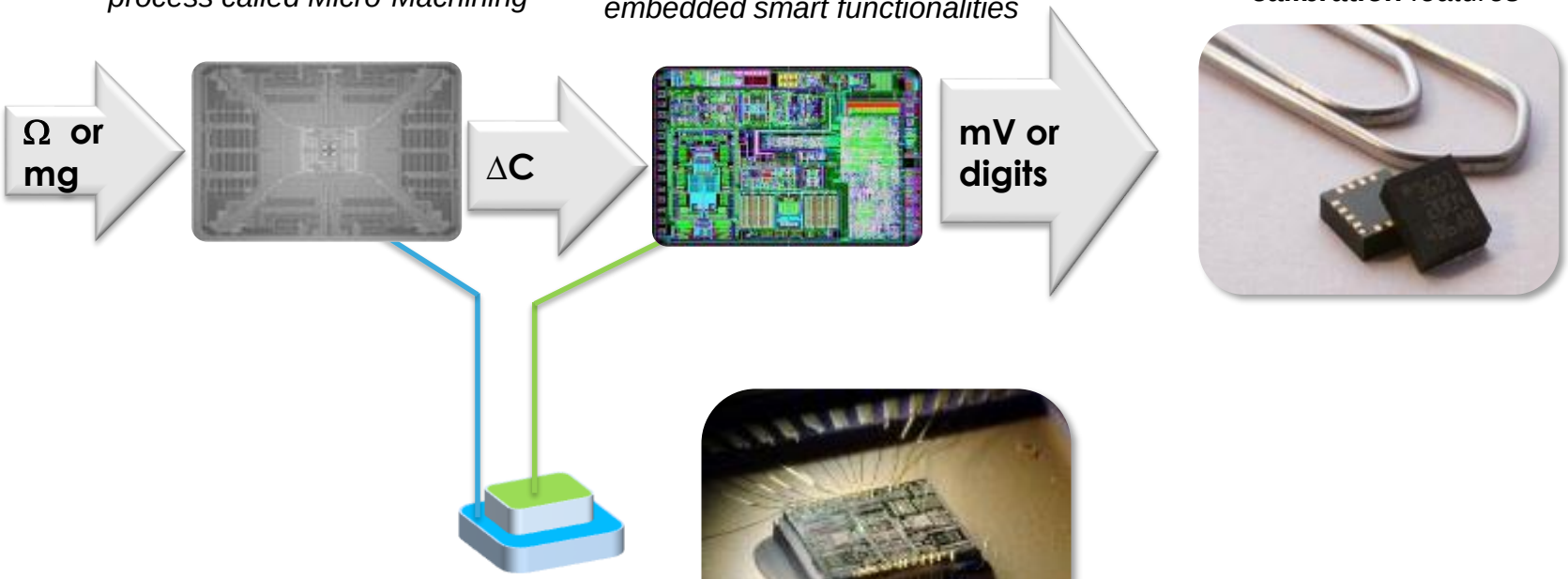
Motion Sensors at a glance

MEMS (**M**icro **E**lectro-**M**echanical **S**ystems) takes advantage of the electrical and mechanical properties of silicon:

Micro Mechanical
Micron-sized Transducer
realized through a specific process called Micro-Machining

ASIC
(ADC + Signal Processing)
Advanced HCMOS Chip *with embedded smart functionalities*

MEMS
Dedicated ***package*** *and* ***calibration*** *features*



Stacked Configuration

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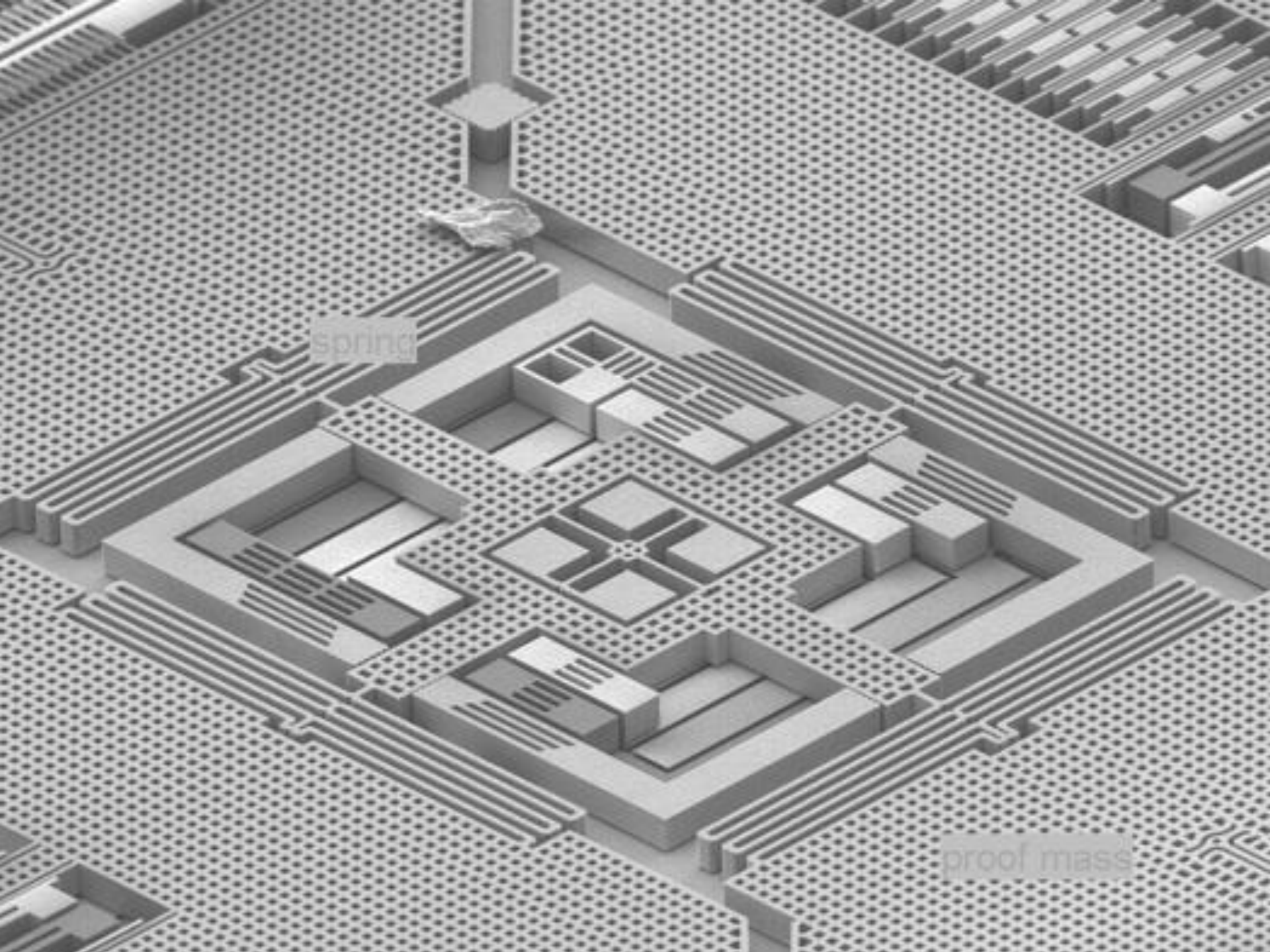
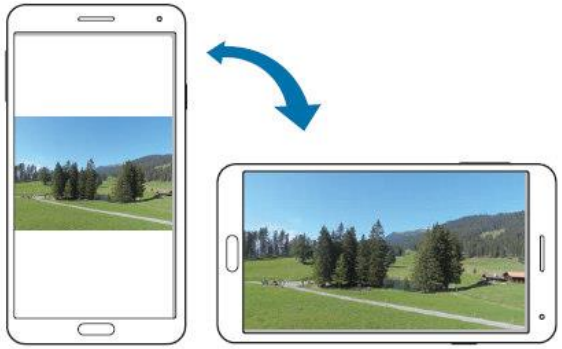
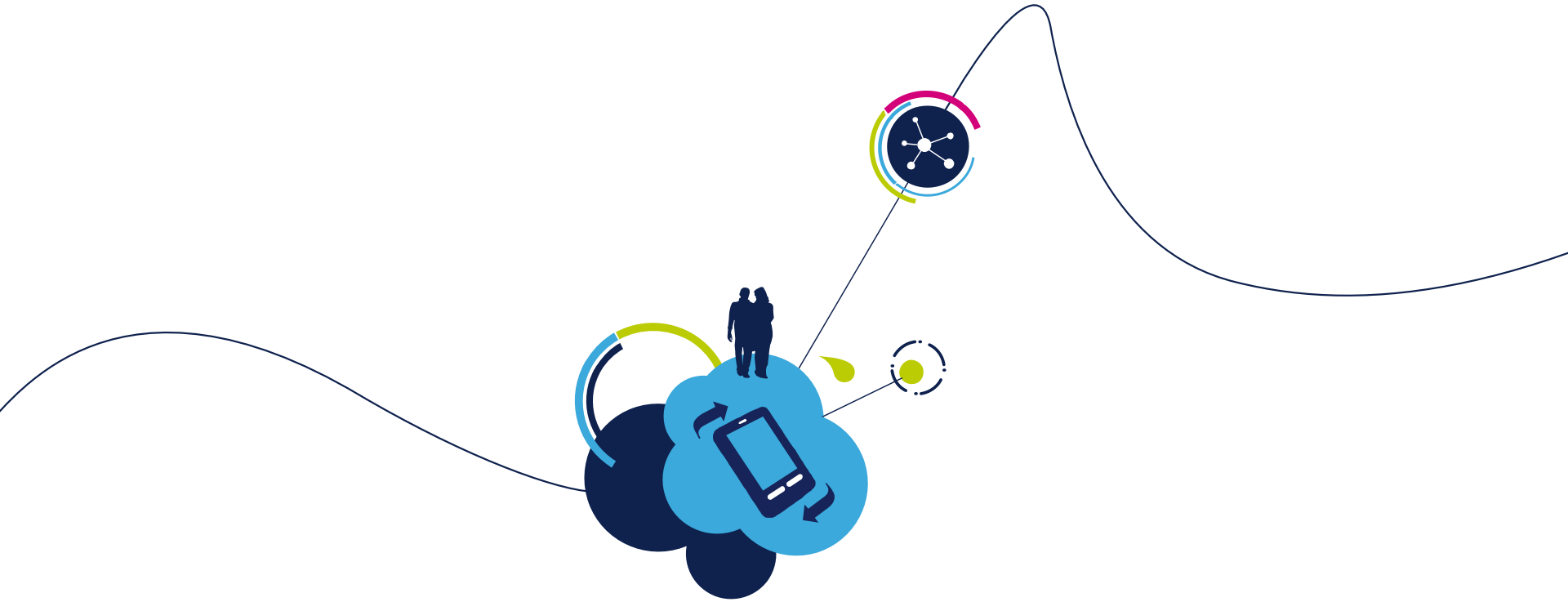

spring
proof mass

?



gravity acceleration!



Accelerometer

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What is an accelerometer?

An accelerometer is a device for measuring accelerations. In normal operating conditions it senses:

- acceleration of gravity
- caused by moving or vibrating the accelerometer

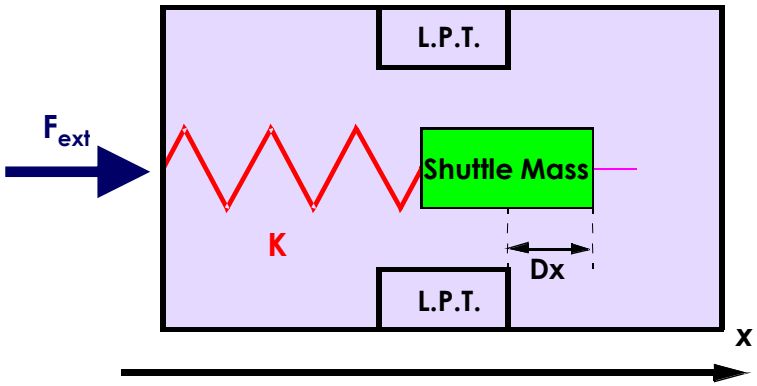
Multi-axis devices are available to detect magnitude and direction of the acceleration vector

What are accelerometer useful for?

Can be used to sense orientation, vibration and shock

How does an Acceleration Sensor work?

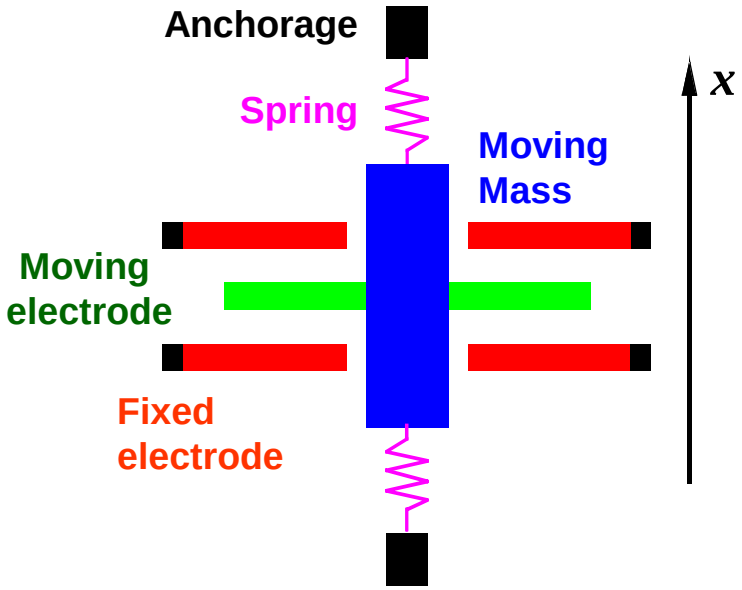
(L.P.T. = Linear position transducer)

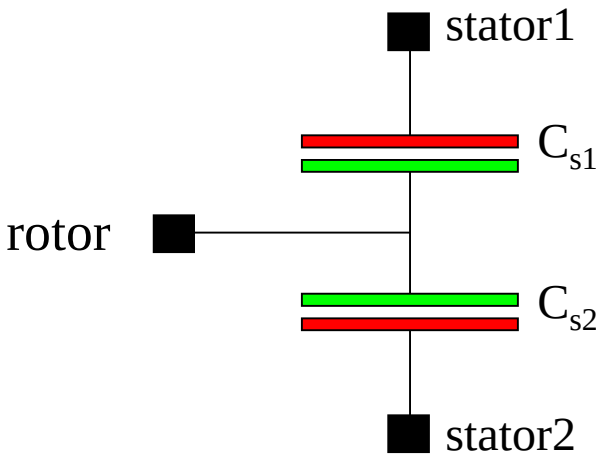


$$F_{ext} = m \cdot a_{ext} = k \cdot \Delta x \quad \Rightarrow \quad a_{ext} = \frac{K}{m} \cdot \Delta x$$

Capacitive effect of displacement

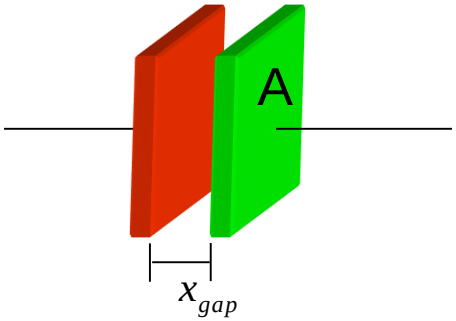
The Linear Position Transducer (L.P.T.) is a Capacitor





Equivalent Circuit

Acceleration from Capacitance Variation



$$C = \varepsilon \frac{A}{x_{gap}}$$

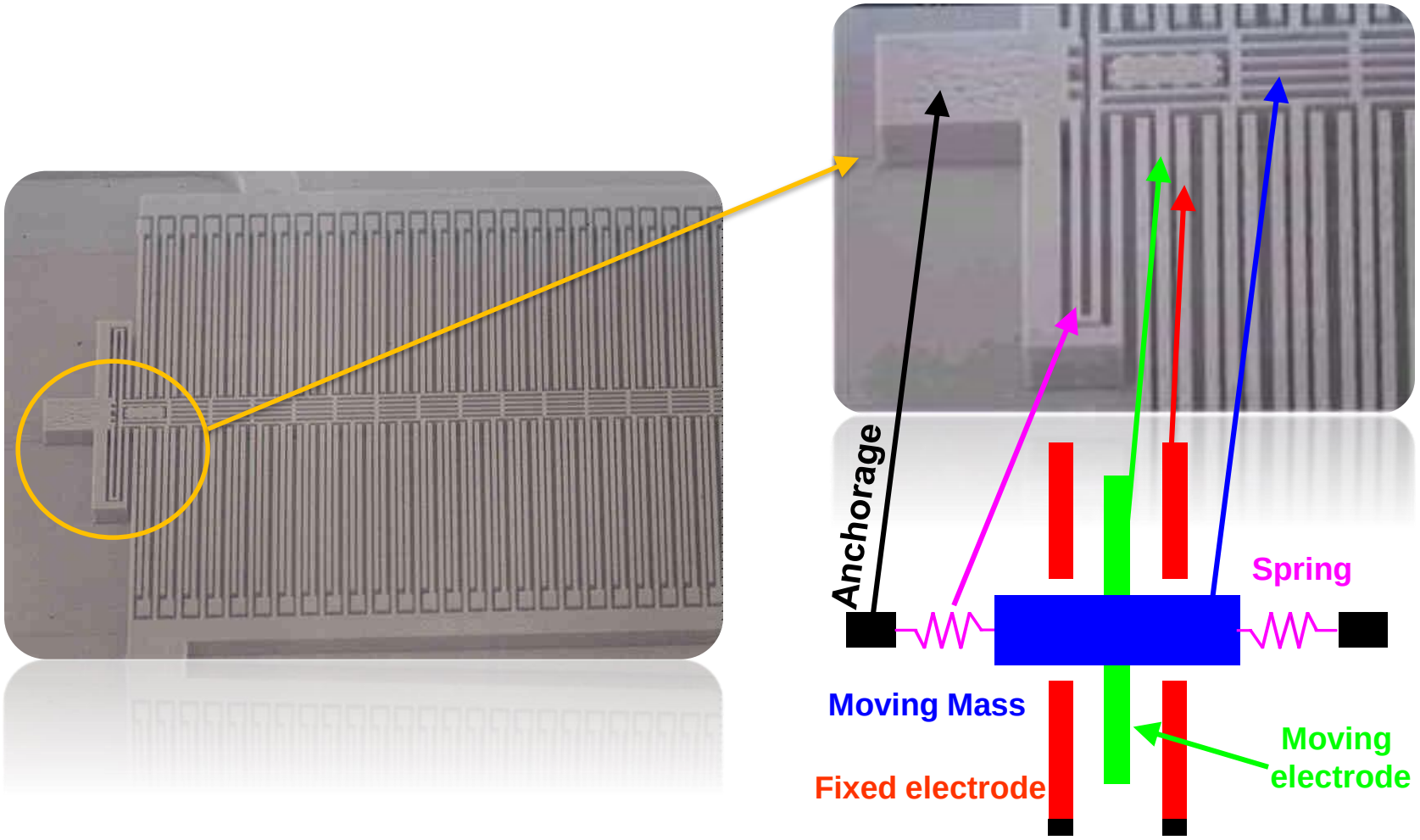
Δx reduction of the gap produces a capacitance increasing of ΔC

$$\Delta C = -\frac{dC}{dx} \cdot \Delta x = \varepsilon \cdot \frac{A}{x_{gap}^2} \cdot \Delta x = C \cdot \frac{\Delta x}{x_{gap}}$$

Measuring the capacitance variation, we can directly obtain the acceleration value:

$$a_{ext} = \frac{K}{m} \cdot \Delta x = \frac{K}{m} \cdot \frac{x_{gap}}{C} \cdot \Delta C$$

Linear Accelerometer Mechanical Structure



Accelerometers key parameters

- **Full Scale (FS)**

  Maximum range of acceleration that can be measured (g, 2g….; g=9.81 m/s2)

- **Zero g Level Offset**

  Describes the actual output signal when there is no acceleration (mg)

  - Volt (for analog output device)
  - mg (for digital output device)

- **Sensitivity (So)**

  Gain of the sensor. Sensitivity can be determinate by applying 1g acceleration to the device itself

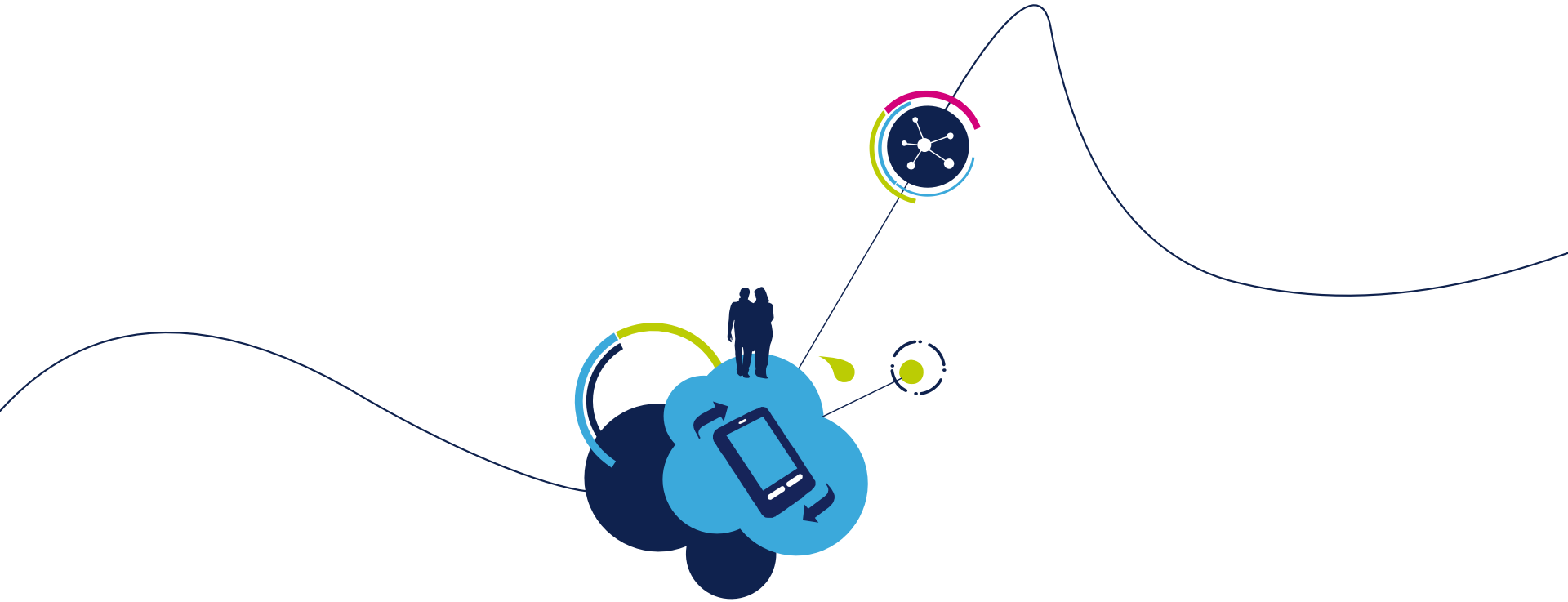
  - Volt/g (for analog output device)
  - mg/digit (for digital output device)

- **Acceleration noise density (An)**

  The output noise will vary depending on the bandwidth. Reducing the bandwidth through low pass filtering helps improving measure resolution. Noise is usually expressed in terms of “Acceleration noise density” [µg/(√Hz)] allowing the user to evaluate, depending on the BW selected, which is the final noise level.

rms = An x √(BW) x Sensitivity

angular speed!



Gyroscope

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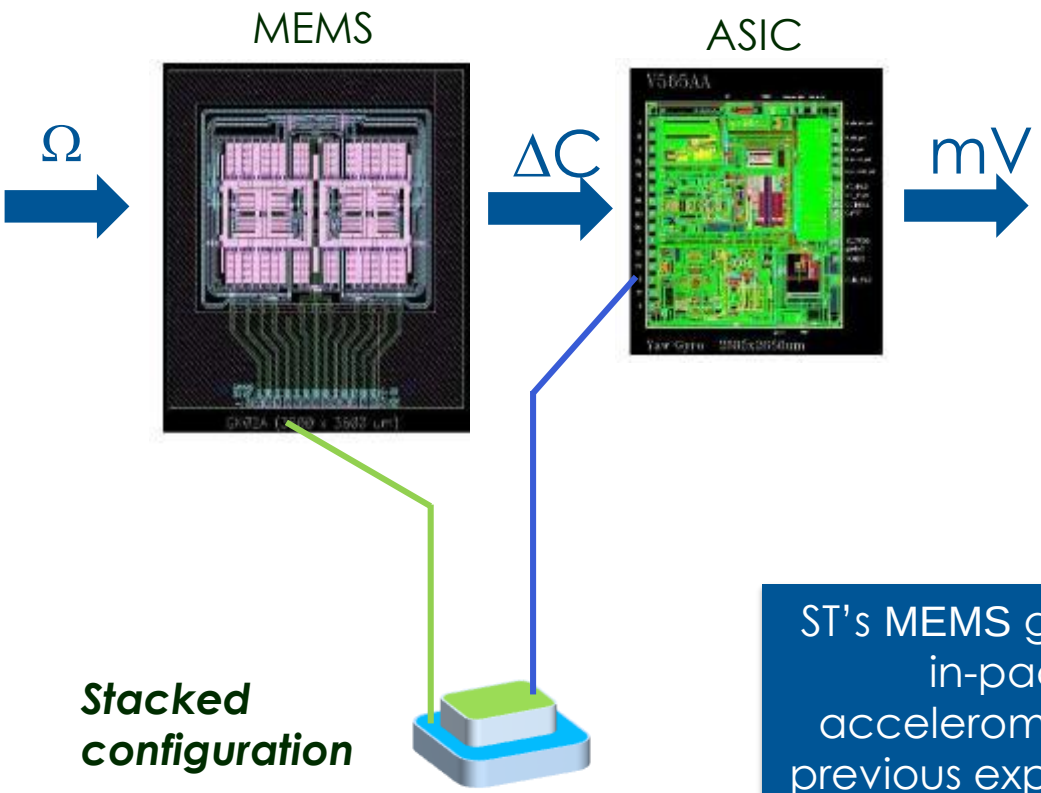
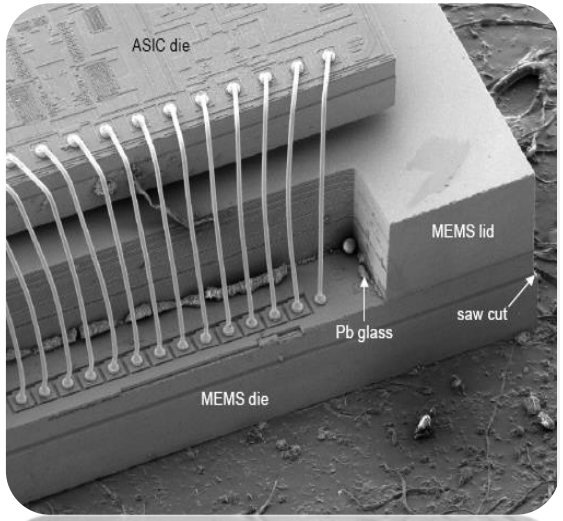
What is a MEMS gyroscope?

ST's MEMS gyroscopes contain the MEMS device itself,
plus the control circuitry required to process the output, all in the same package





ST's MEMS gyroscopes use the same system-in-package approach as MEMS accelerometers, enabling prompt reuse of previous expertise and allowing high flexibility and fast time to market

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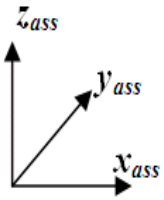
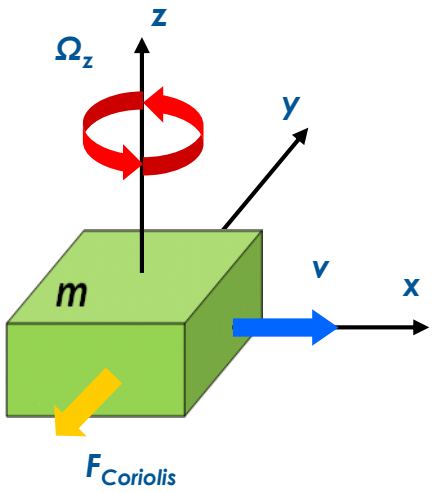
MEMS gyroscopes - the Coriolis effect





MEMS gyroscopes use the Coriolis effect.

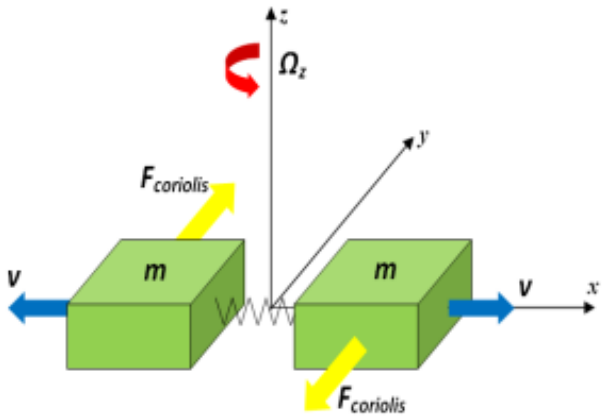
Consider a mass moving in direction **v** **(blue arrow)**. When an angular movement is applied **(red arrow)**, the mass experiences a force in the direction of the **yellow arrow** as a result of the Coriolis effect.

In a MEMS gyroscope, the resulting physical displacement is then read using a capacitive sensing interface.

$$F_{Coriolis} = -2m\boldsymbol{\Omega}_z \Lambda \boldsymbol{v}$$

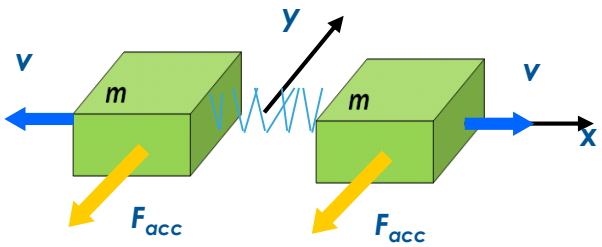
MEMS gyroscopes - tuning fork design

Angular rate is applied



$\Delta C \neq 0$

Acceleration is applied



$\Delta C = 0$

ST's MEMS gyroscopes use a tuning fork configuration. Two masses oscillate, moving constantly in opposite directions (see **v** in the figure). When an angular velocity is applied, the Coriolis force on each mass also acts in opposite directions.

The differential value in capacitance is then used to measure the rotation.

When, instead, linear acceleration is applied to the two masses, they move in the same direction, and the differential capacitance is zero.

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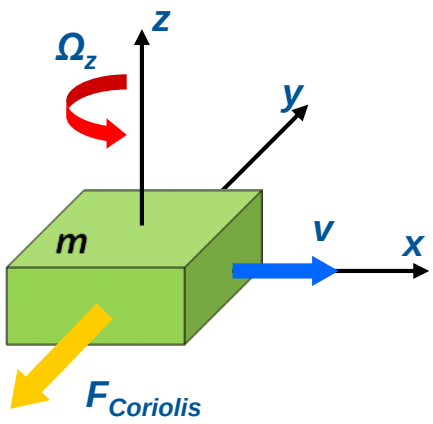
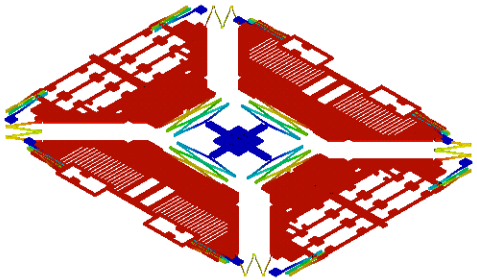
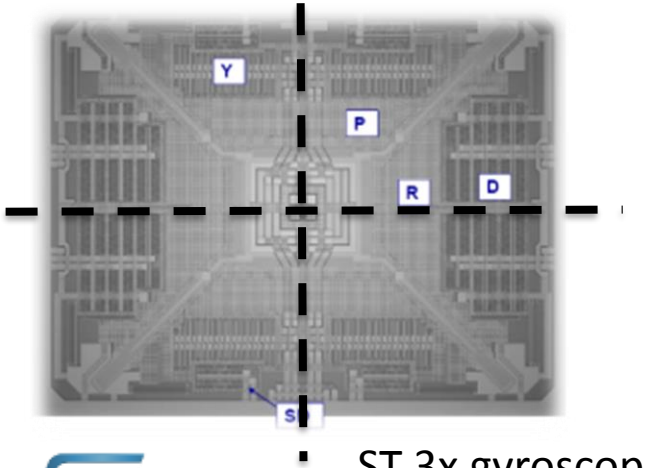
…MEMS gyroscopes sense and drive

3-axis digital gyroscope



Drive mode

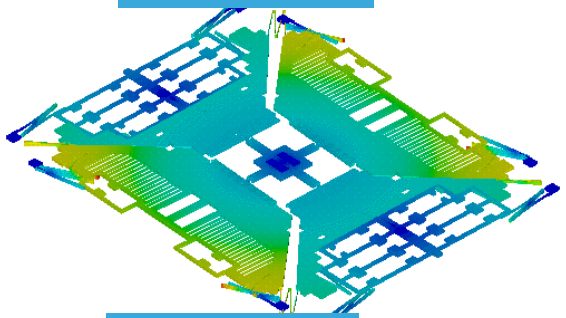




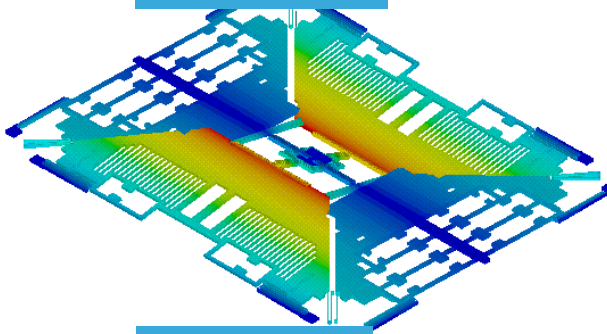
Single driving Mass

ST 3x gyroscope

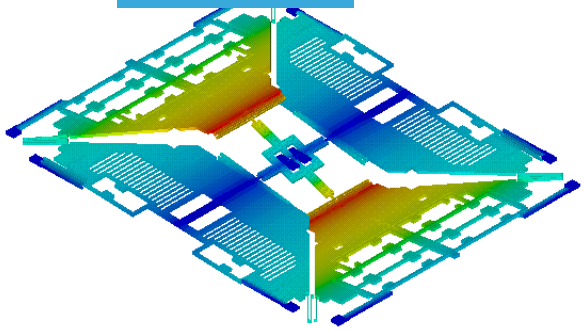
Yaw mode



Pitch mode



Roll mode



Gyroscope key parameters

- **Full Scale (FS)**

  Maximum range of angular rate that can be measured (degree per seconds)

- **Zero rate Level**

  Sensor output (analog/digital) when no angular rate is applied, specified as a typical value over a certain accuracy range (dps)

- **Sensitivity (So)**

  Gain of the sensor as ratio between angular rate and the output value (mdps/digit)

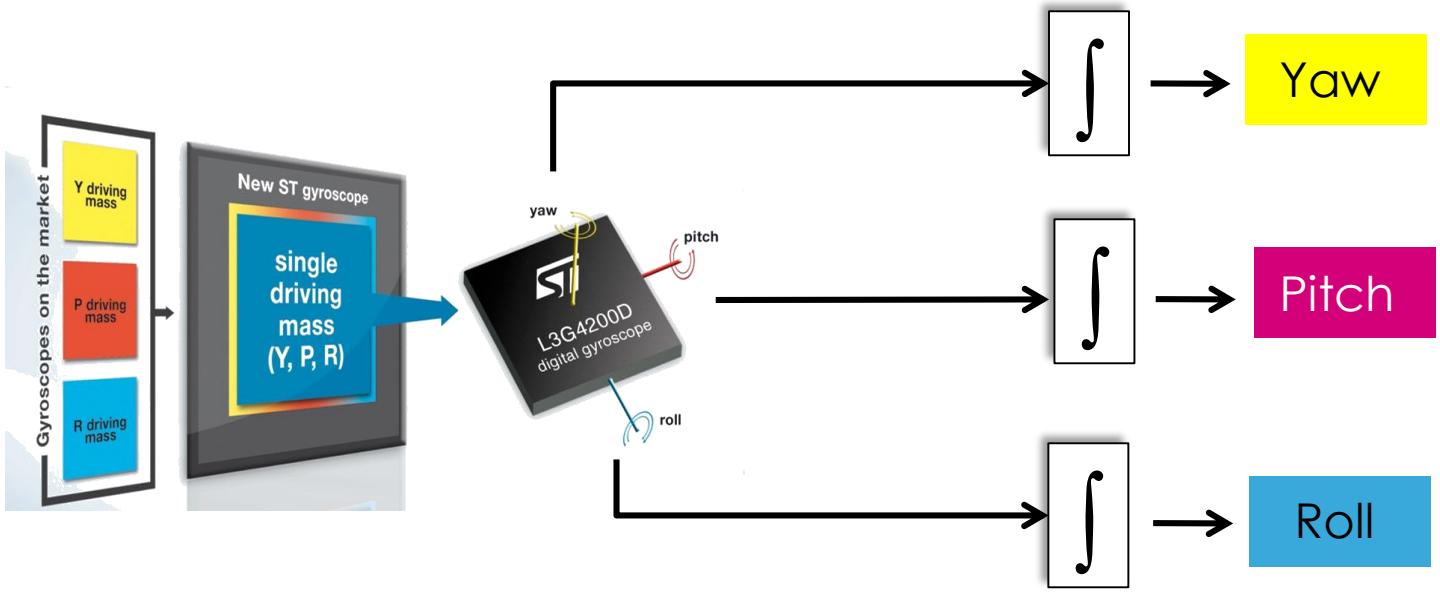
- **Rate noise density (Rn)**

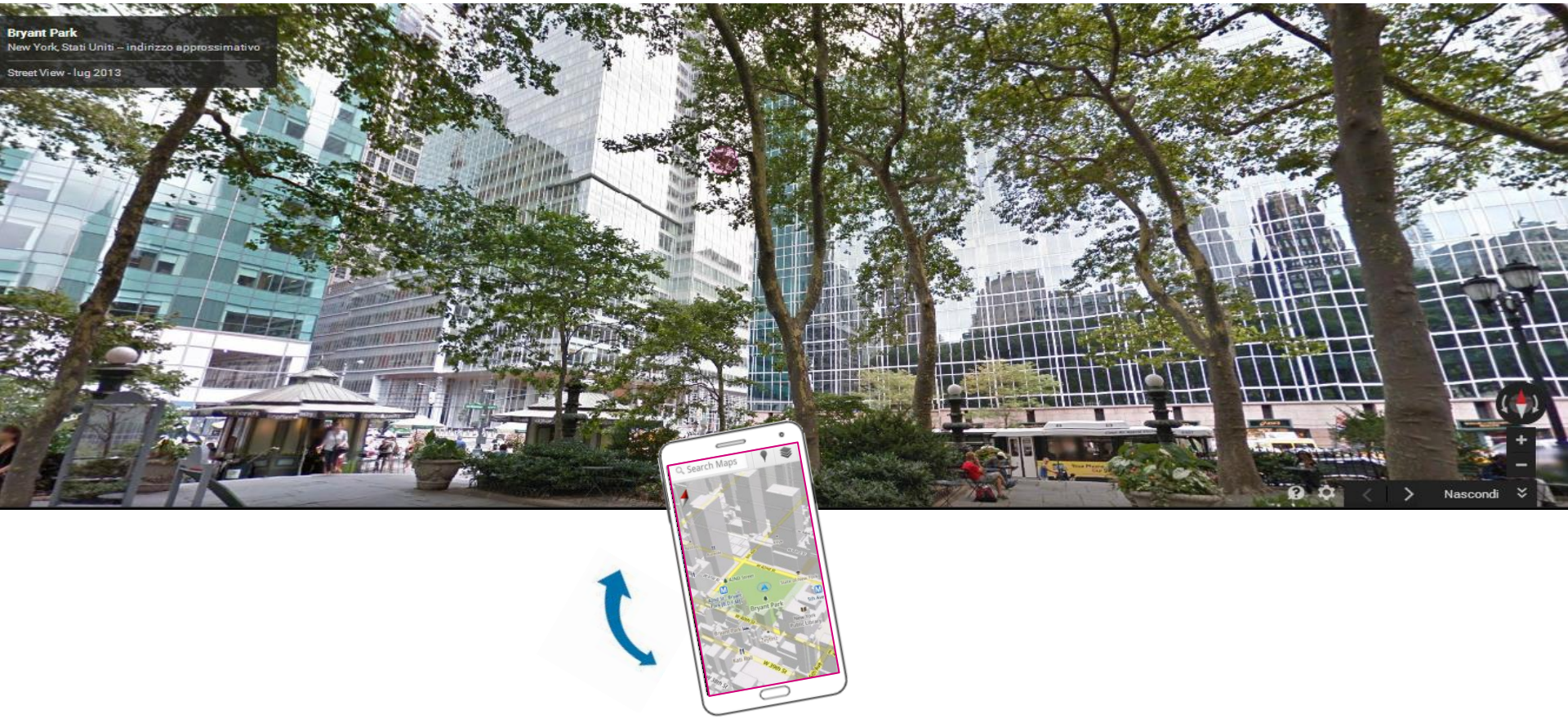
  The output noise will vary depending on the bandwidth. Reducing the bandwidth through low pass filtering helps improving measure resolution. Noise is usually expressed in terms of “Rate noise density” [dps/(√Hz)] allowing the user to evaluate, depending on the BW selected, which is the final noise level.

  rms = Rn x √(BW) x Sensitivity

Theory of operation

- MEMS gyroscopes measure angular rate using the Coriolis effect.
- Angular variation can be computed using an angular rate integration





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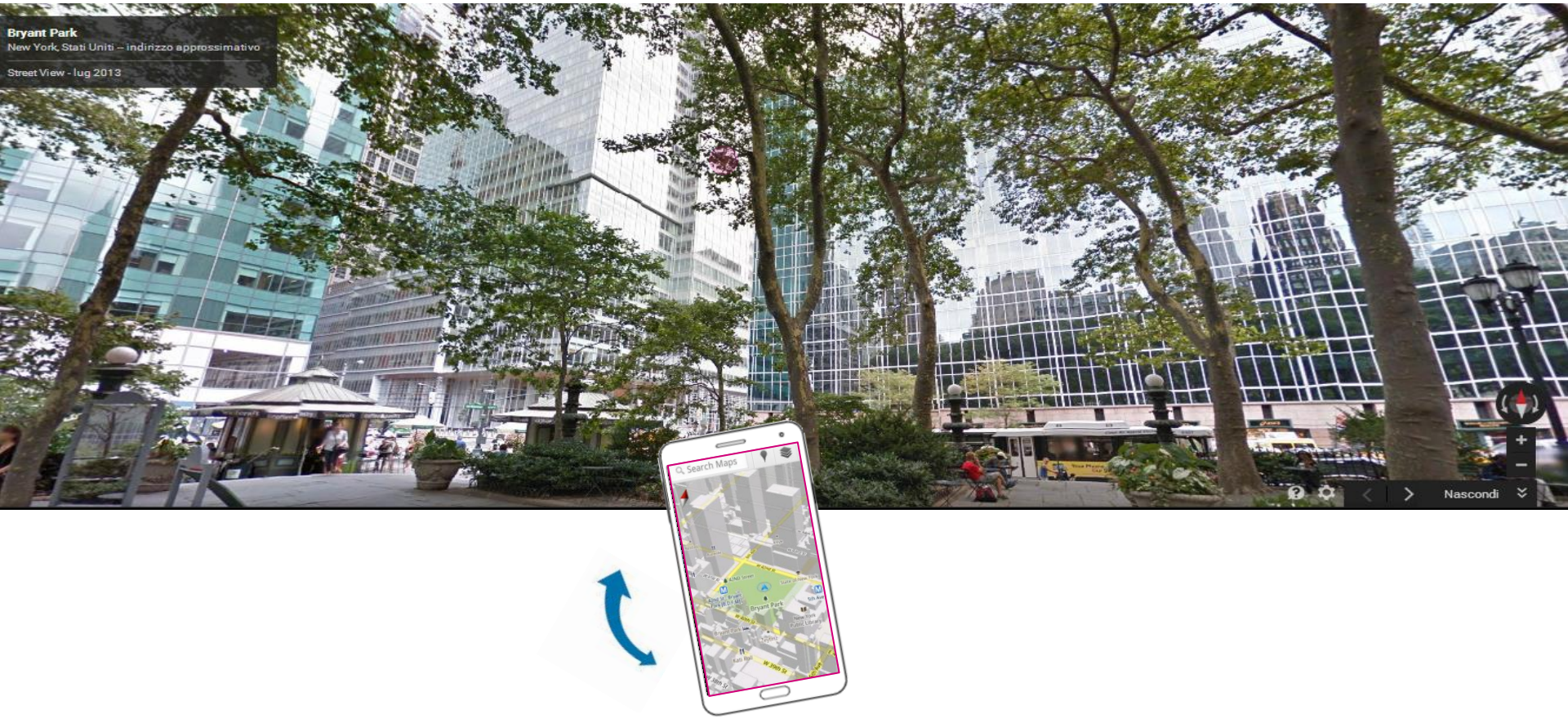

magnetic field!

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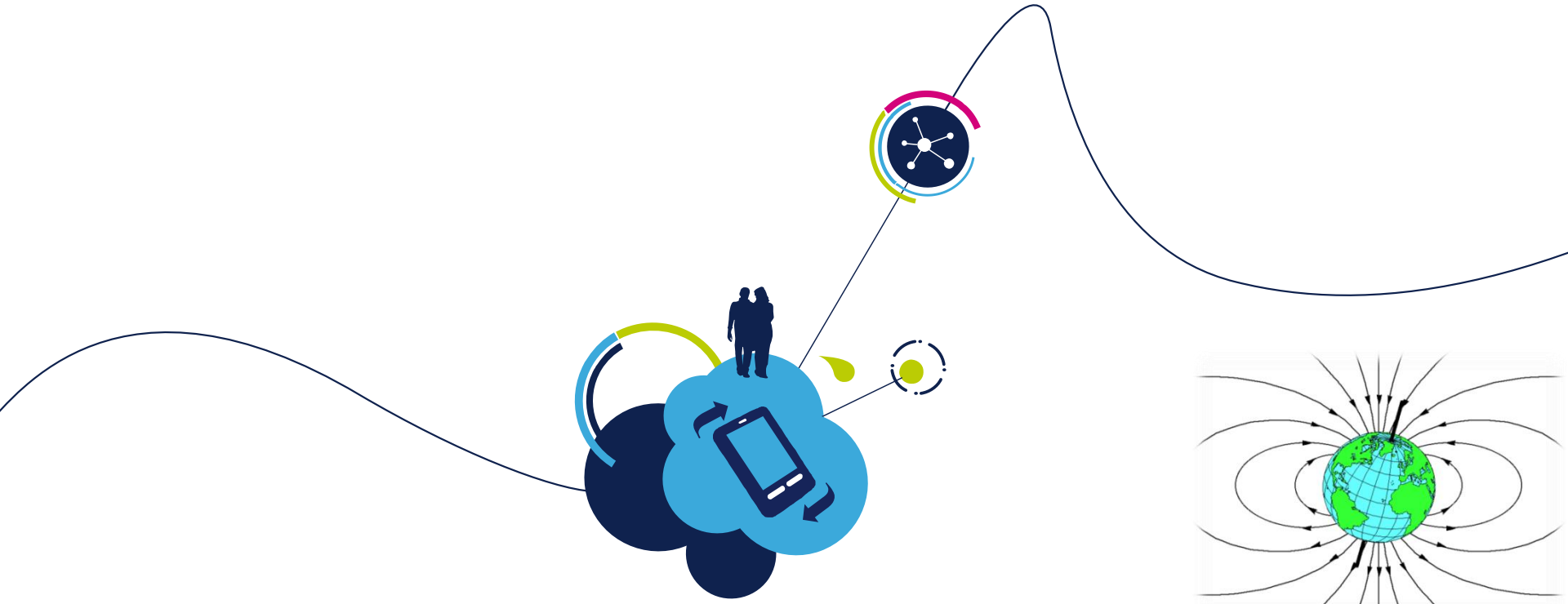

Magnetometer

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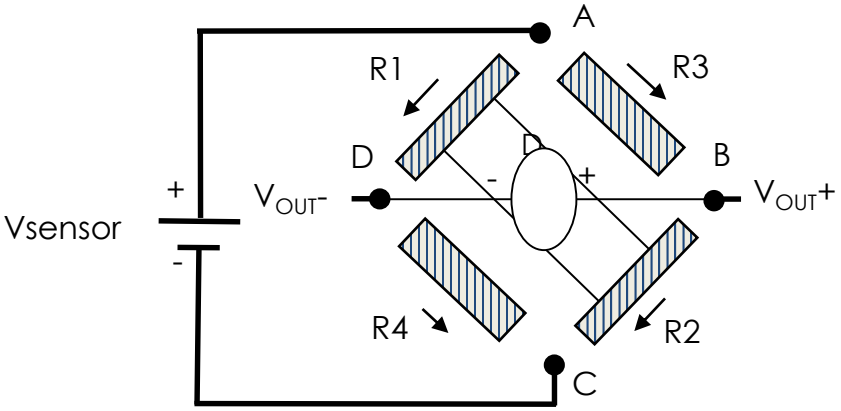
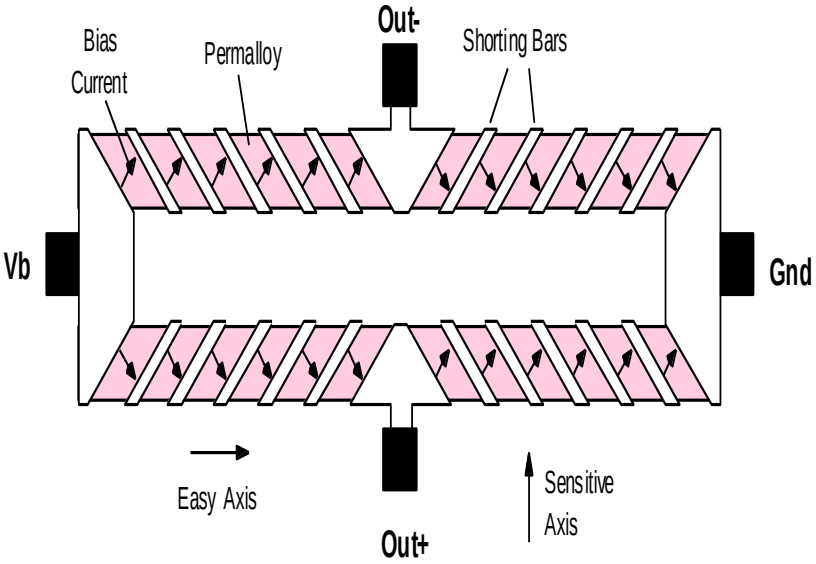
Magnetometer Sensors

Anisotropic Magneto-Resistive (AMR) Sensors are Wheatstone Bridges made of thin film resistors.

- The magneto-resistive elements are made of a Permalloy (NiFe thin film material). Slight resistance changes are obtained with applied magnetic fields .

- In the presence of a magnetic field, a change in resistance will cause a change in differential output voltage.





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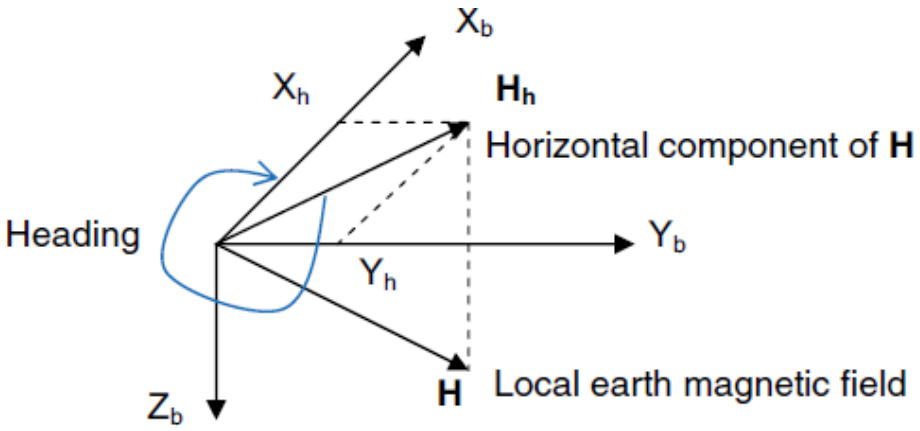
3-axis Magnetometer: Heading measurement

Theory of operation

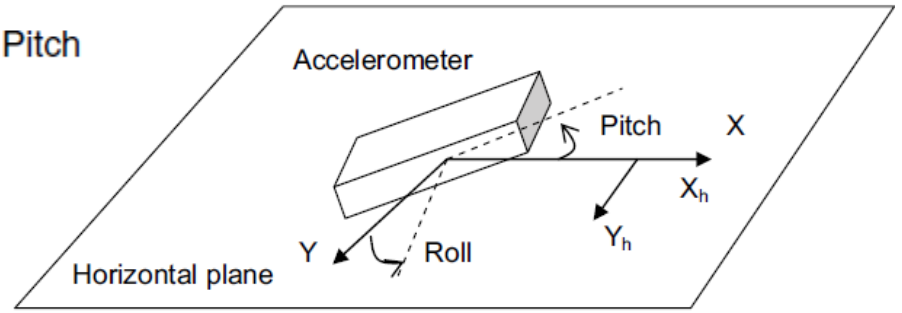
- Local earth magnetic field H has a fixed component H_h on the horizontal plane pointing to the earth's magnetic north. This component can be measured by the magnetic sensor sensing axes X_M and Y_M that are named as X_h and Y_h.

Heading = arctan(Yh / Xh)



If the handheld device is tilted :

$$X_h = X_M \cos Pitch + Z_M \sin Pitch$$
$$Y_h = X_M \sin Roll \sin Pitch + Y_M \cos Roll - Z_M \sin Roll \cos Pitch$$



Further Sensors

Humidity sensors

A planar capacitance technology that integrates humidity & temp. sensors in the sensing element.

View products

iNEMO inertial modules

Offer more compact, robust, and easy-to-assemble solutions compared to discrete MEMS products.

View products

MEMS microphones

For all audio applications where small size, high sound quality, reliability & affordability are required.

View products

Pressure sensors

Innovative MEMS techno to provide extremely high pressure resolution, in ultra-compact & thin packages.

View products

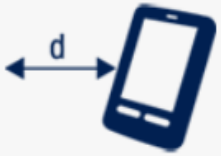
Temperature sensors

Use in a wide range of applications: industrial, consumer, medical and computer market segments.

Touch sensors

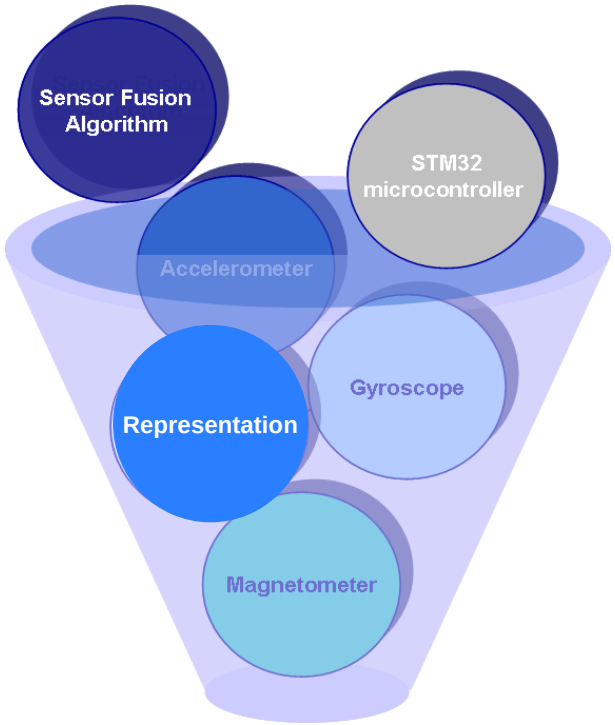
Provide true multi-touch capability, supporting unlimited simultaneous touches.

Proximity sensors



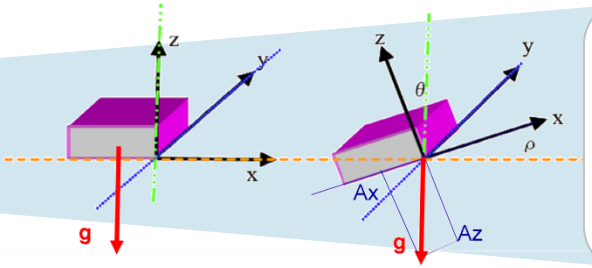
FlightSense technology can be used in a host of application areas where accurate ranging is required.

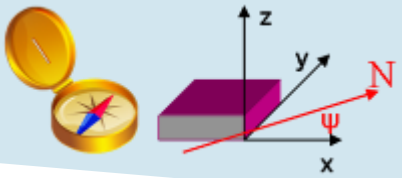
Sensor Fusion

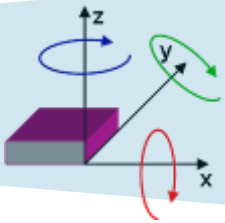


3D-Orientation

Sensor fusion for 3D space orientation







- The **accelerometer** senses the linear acceleration.
- In **static** conditions, the projection of gravity on the three axes allow to compute **tilt angles**

- The **magnetometer** senses the magnetic field.
- In **static** conditions, the projection of geomagnetic field on the three axes allows to compute heading angle

- The **Gyroscope** measures the angular rate applied to the device
- In **dynamic** conditions, by integration of the 3 axis angular rate the 3D orientations can be computes

IMU (**I**nertial **M**easurement **U**nit) allows sensor fusion and opens new application

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Motion MEMS and environmental sensors expansion board

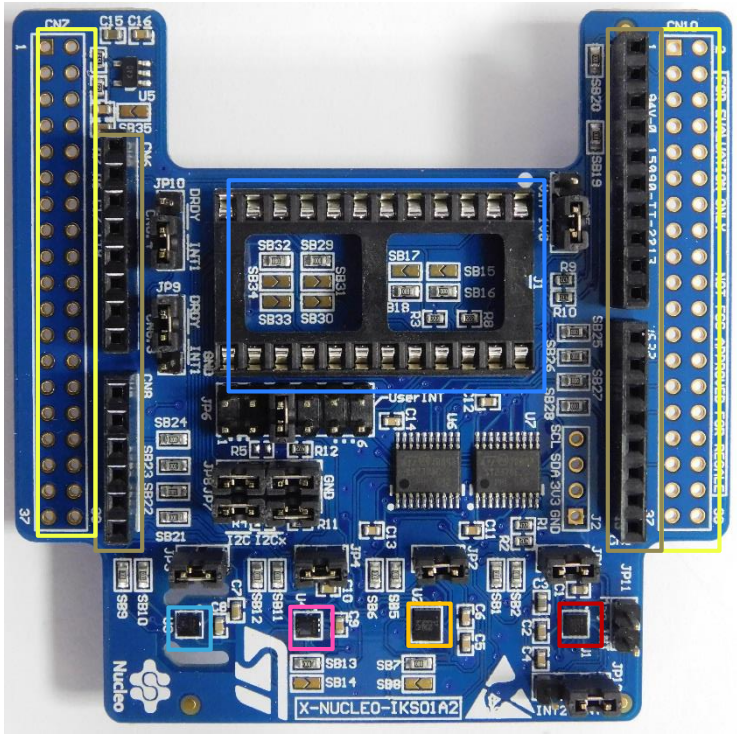
Hardware Overview (1/3)

X-NUCLEO-IKS01A2 Hardware Description

- The X-NUCLEO-IKS01A2 is a motion MEMS and environmental sensor evaluation board system.
- It is compatible with the Arduino UNO R3 connector layout, and is designed around ST's latest sensors.

Key Product on board

LSM6DSL
MEMS 3D accelerometer (±2/±4/±8/±16 g) + 3D gyroscope (±125/±245/±500/±1000/±2000 dps)
LSM303AGR
MEMS 3D magnetometer (±50 gauss) + MEMS 3D accelerometer (±2/±4/±8/±16 g)
LPS22HB
MEMS pressure sensor, 260-1260 hPa absolute digital output barometer
HTS221
Capacitive digital relative humidity and temperature
DIL 24-pin
Socket available for additional MEMS adapters and other sensors (UV index)



HTS221 LSM6DSL ST morpho connector**
LPS22HB LSM303AGR Arduino UNO R3 connector
DIL 24-pin

Latest info available at www.st.com
X-NUCLEO-IKS01A2

** Connector for the STM32 Nucleo Board

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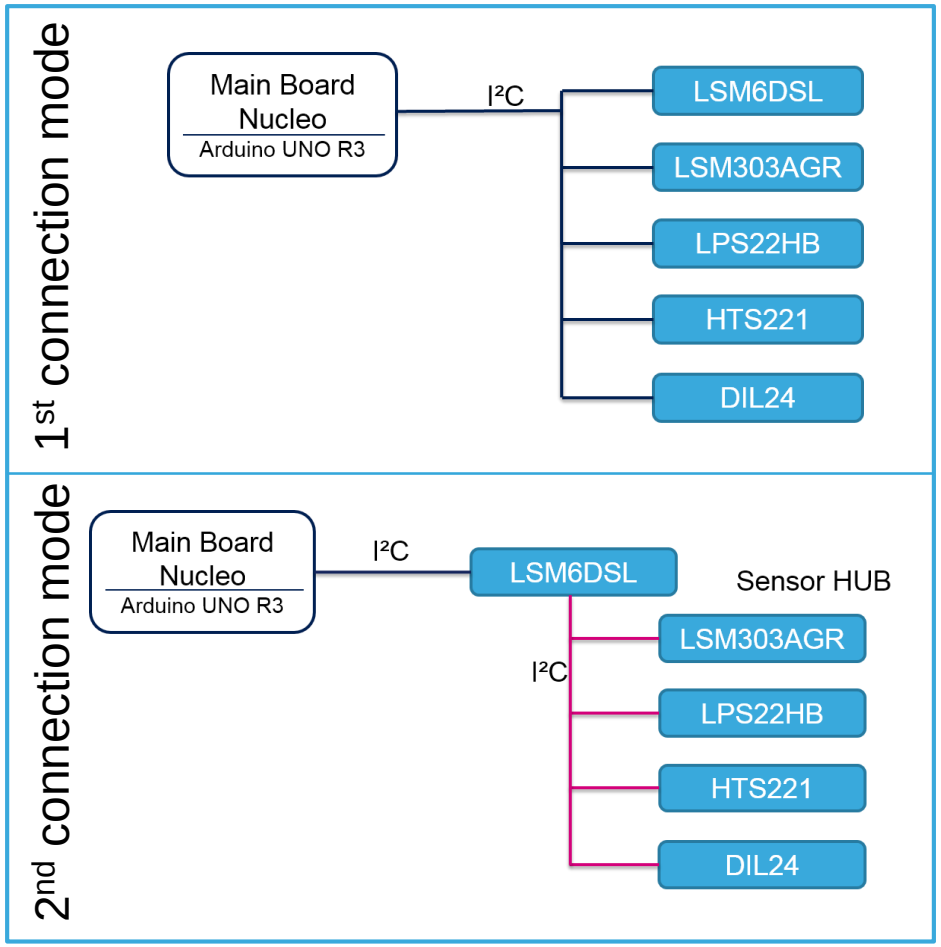
Motion MEMS and environmental sensor expansion board

Hardware overview (2/3)

Key features

- The X-NUCLEO-IKS01A2 is a motion MEMS and environmental sensor evaluation board system.
- All sensors are connected on a single I²C bus or could be managed by a Sensor HUB
- Sensor I²C address selection
- DIL24 socket (compatible with STEVAL-MKI***V* MEMS adapter boards)



Representative of a DIL24 board

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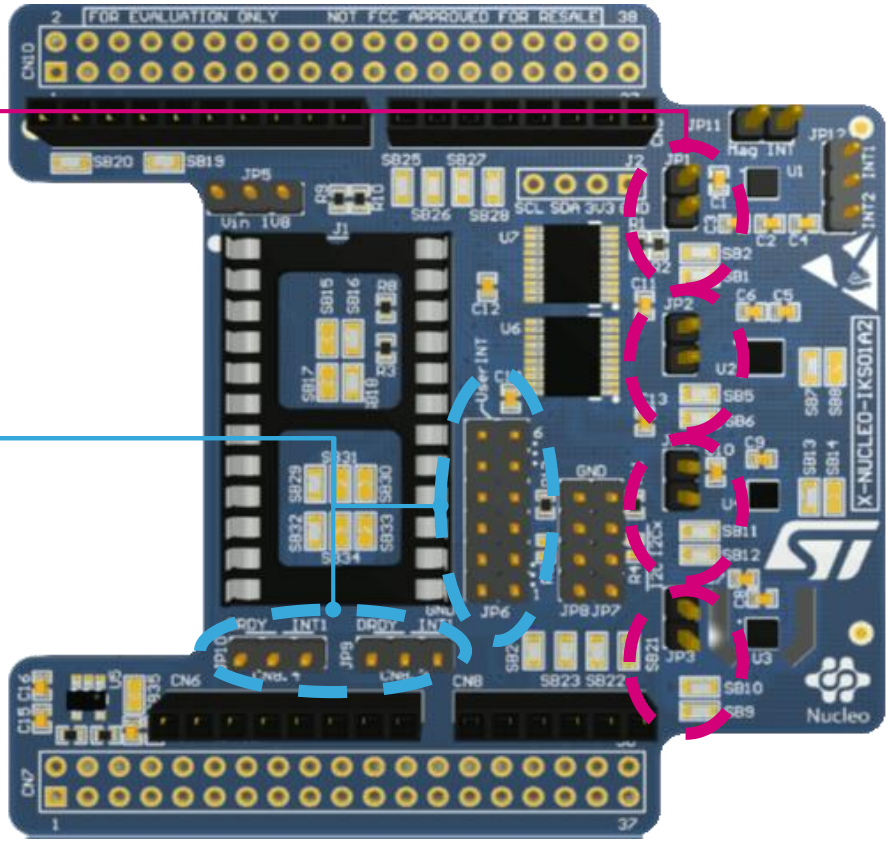
* is used as a wildcard character for related part number

Motion MEMS and environmental sensor expansion board

Hardware overview (3/3)

Key features

- Sensor disconnection (disconnects the I²C bus as well as the power supply allowing power consumption measurements)
- Interrupt and DRDY signals from sensors could be re-directed.



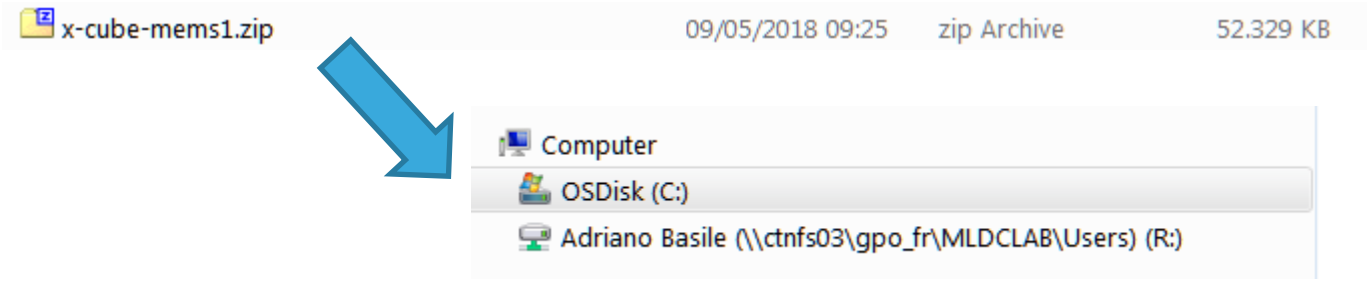
Check Point

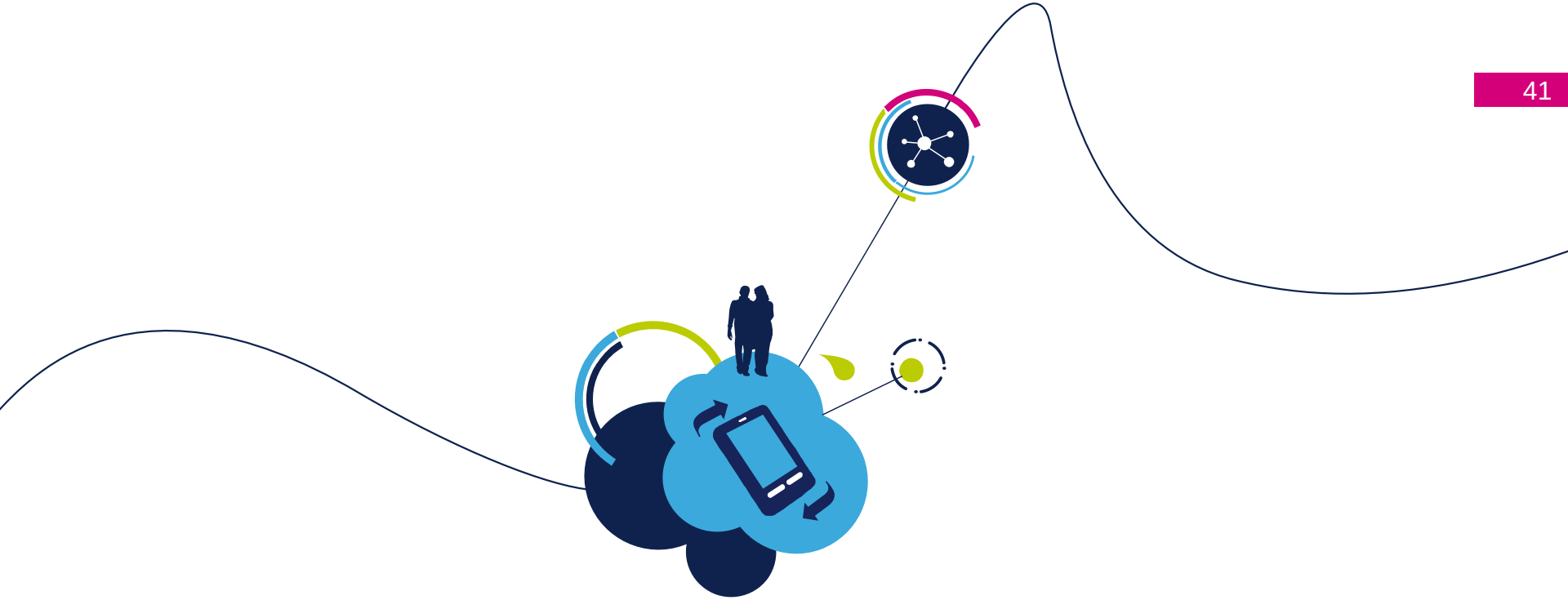
Libreria firmware per i sensori MEMS

http://www.st.com/content/st_com/en/products/embedded-software/mcus-embedded-software/stm32-embedded-software/stm32cube-expansion-packages/x-cube-mems1.html

Interfaccia PC

http://www.st.com/content/st_com/en/products/embedded-software/evaluation-tool-software/unicleo-gui.html





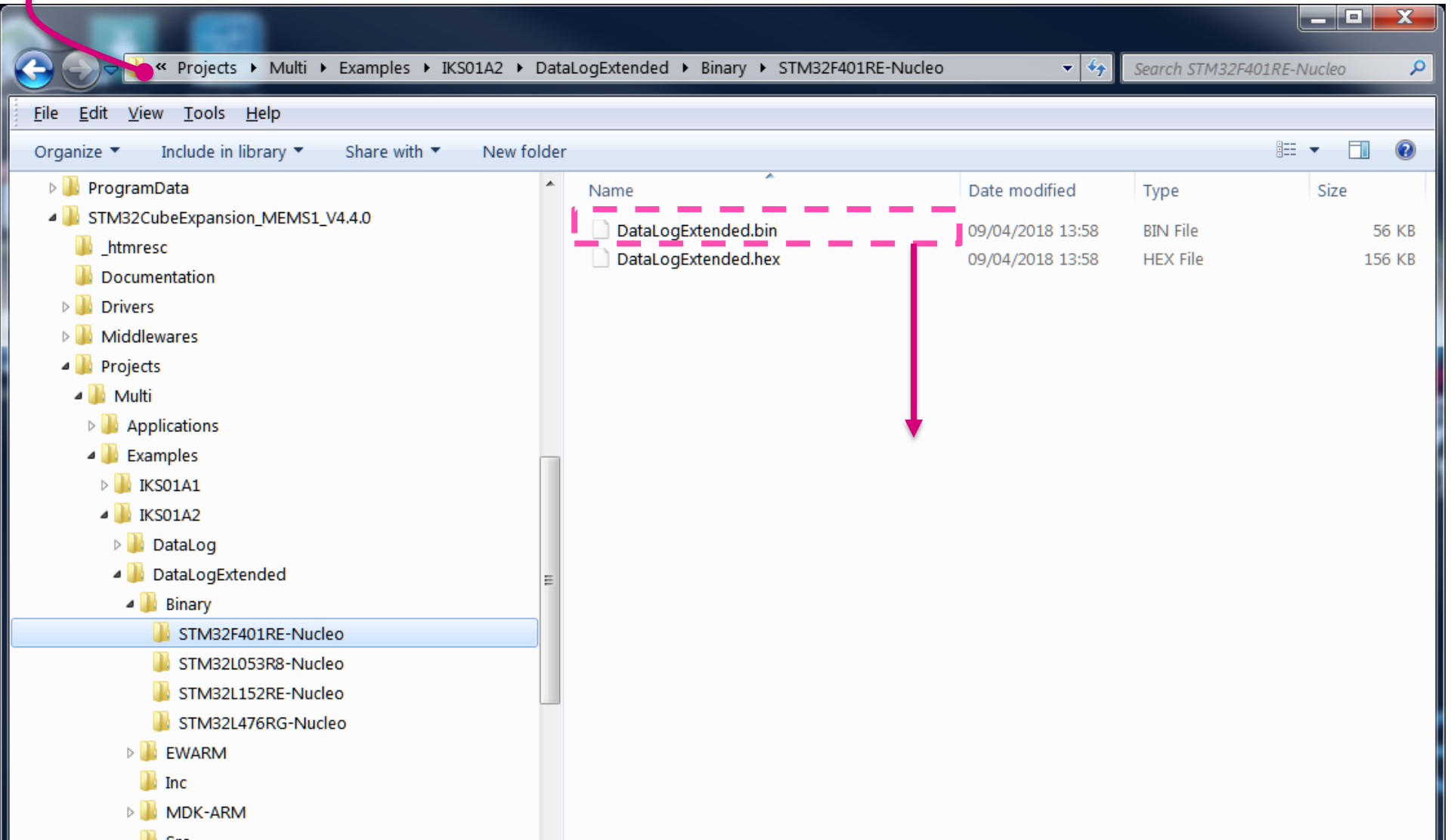
Go Live!

Read Release Note

C:\STM32CubeExpansion_MEMS1_V4.4.0\Release_Notes.html

DataLogExtended

C:\STM32CubeExpansion_MEMS1_V4.4.0\Projects\Multi\Examples\IKS01A2\DataLogExtended\Binary\STM32F401RE-Nucleo



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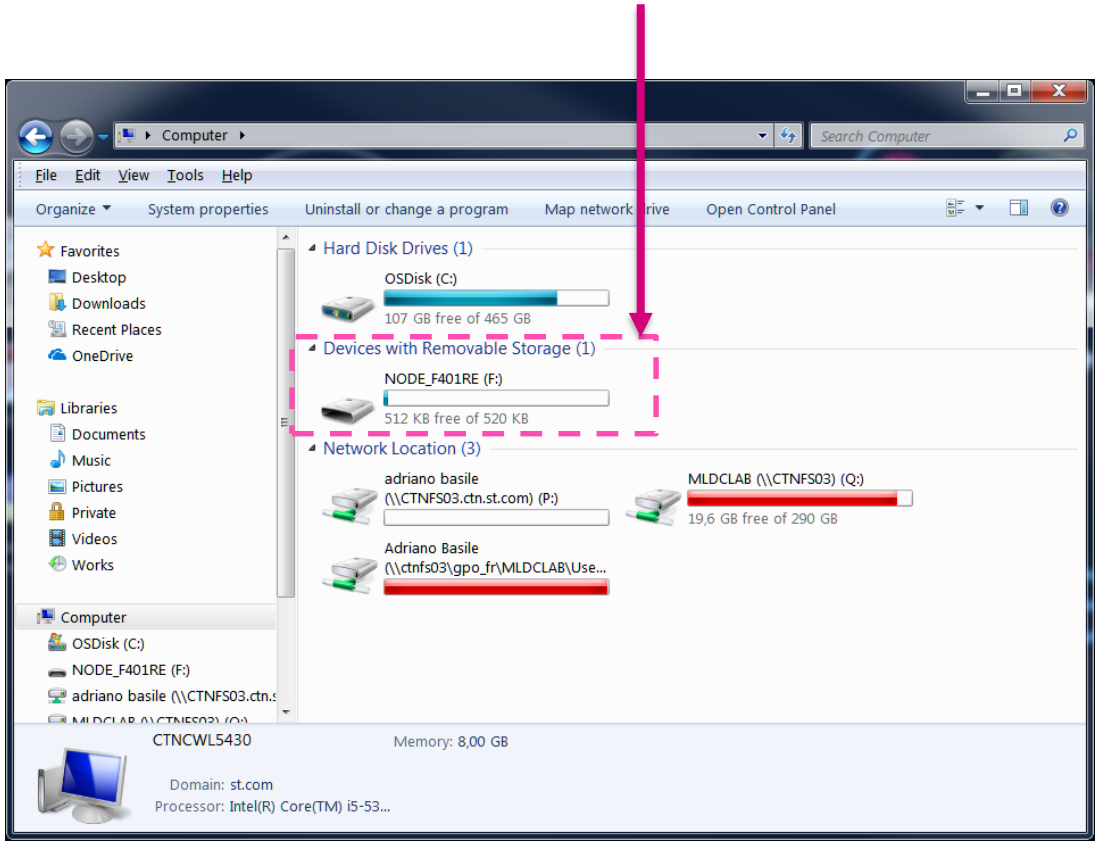
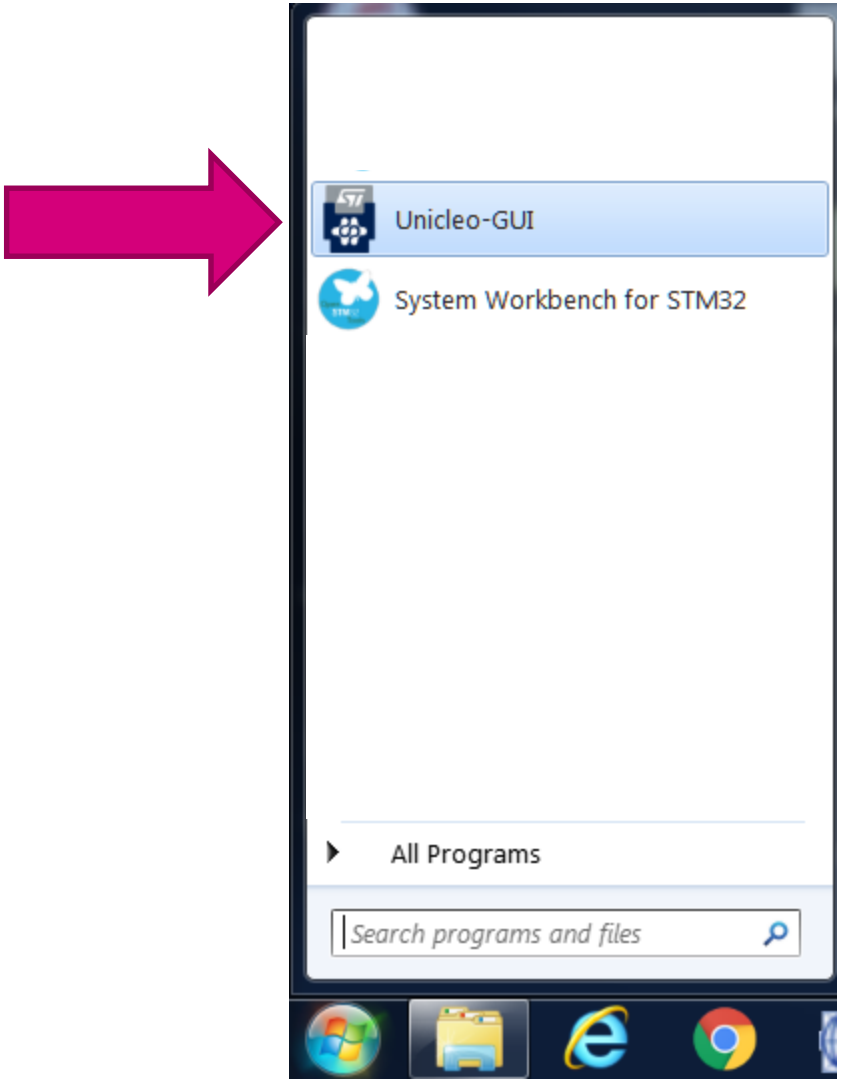
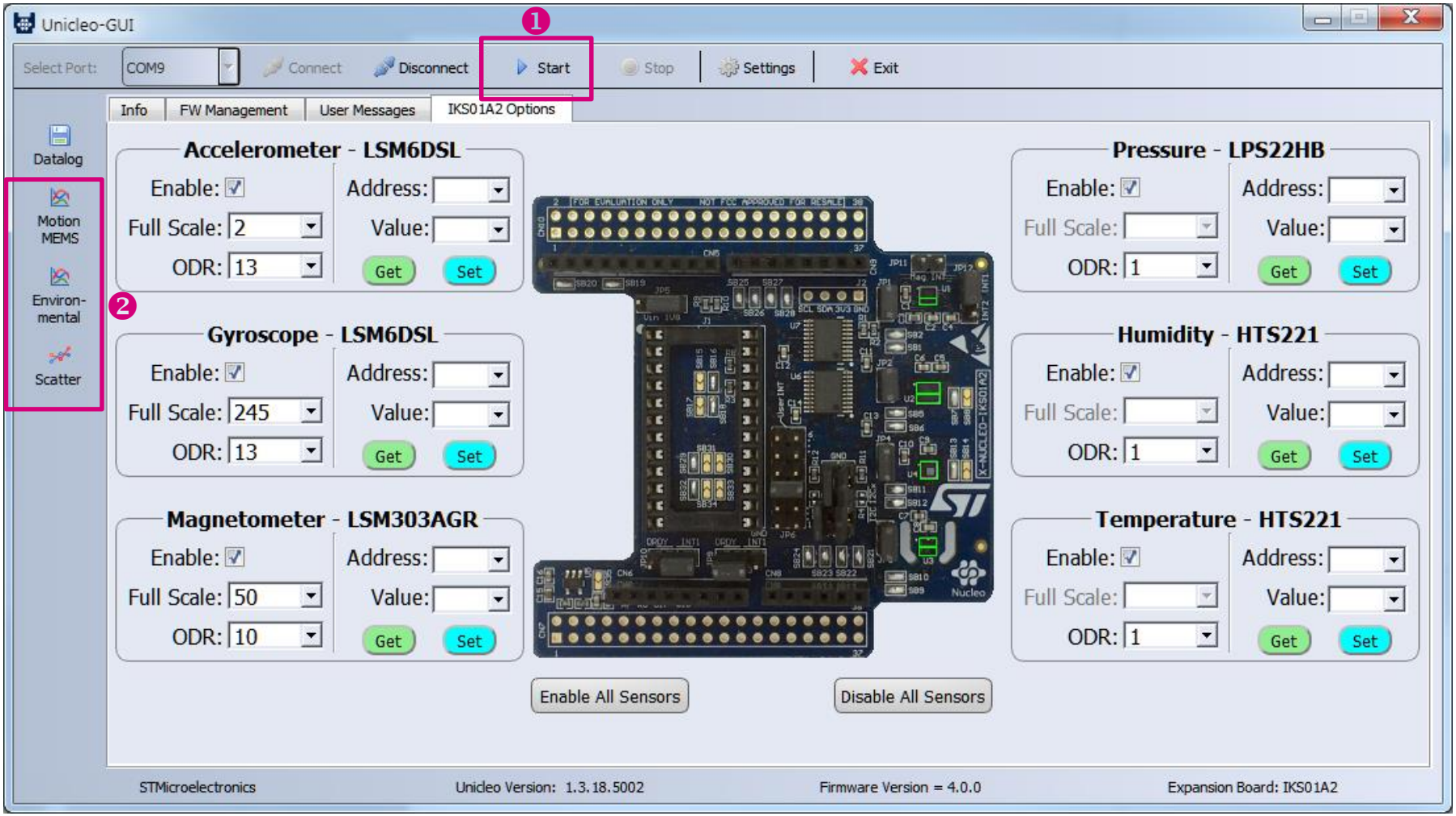


Launch Unicleo-GUI



Play Unicleo-GUI



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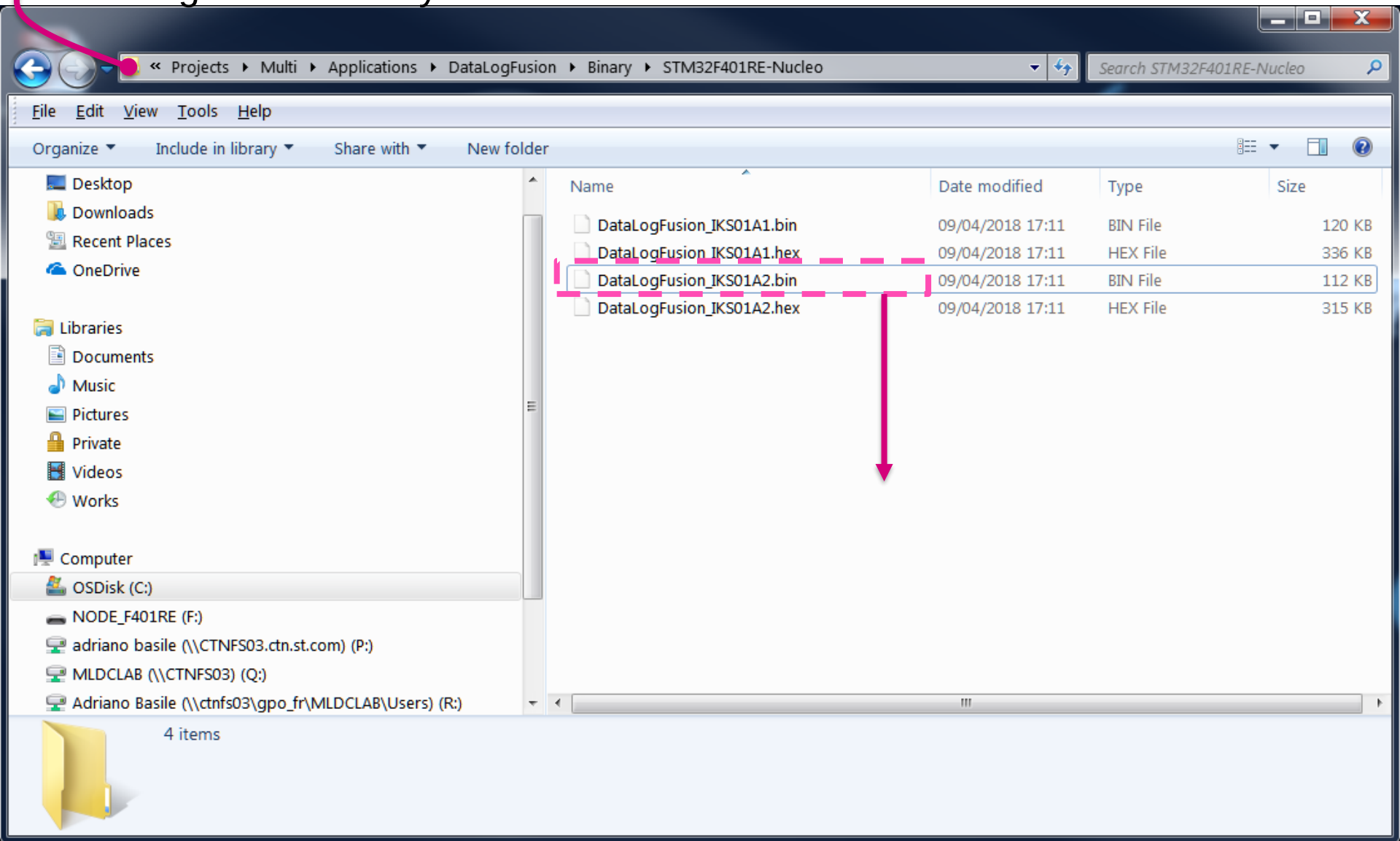
DataLogFusion

C:\STM32CubeExpansion_MEMS1_V4.4.0\Projects\Multi\Applications\DataLogFusion\Binary\STM32F401RE-Nucleo



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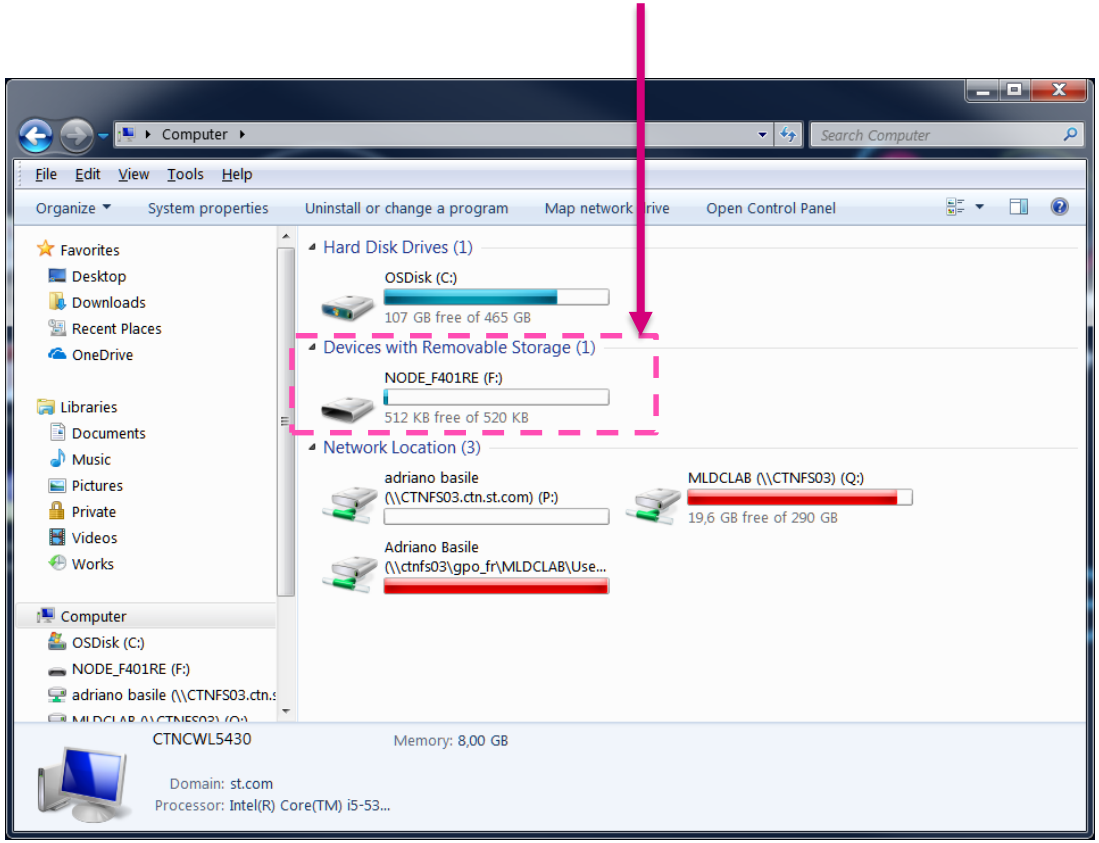
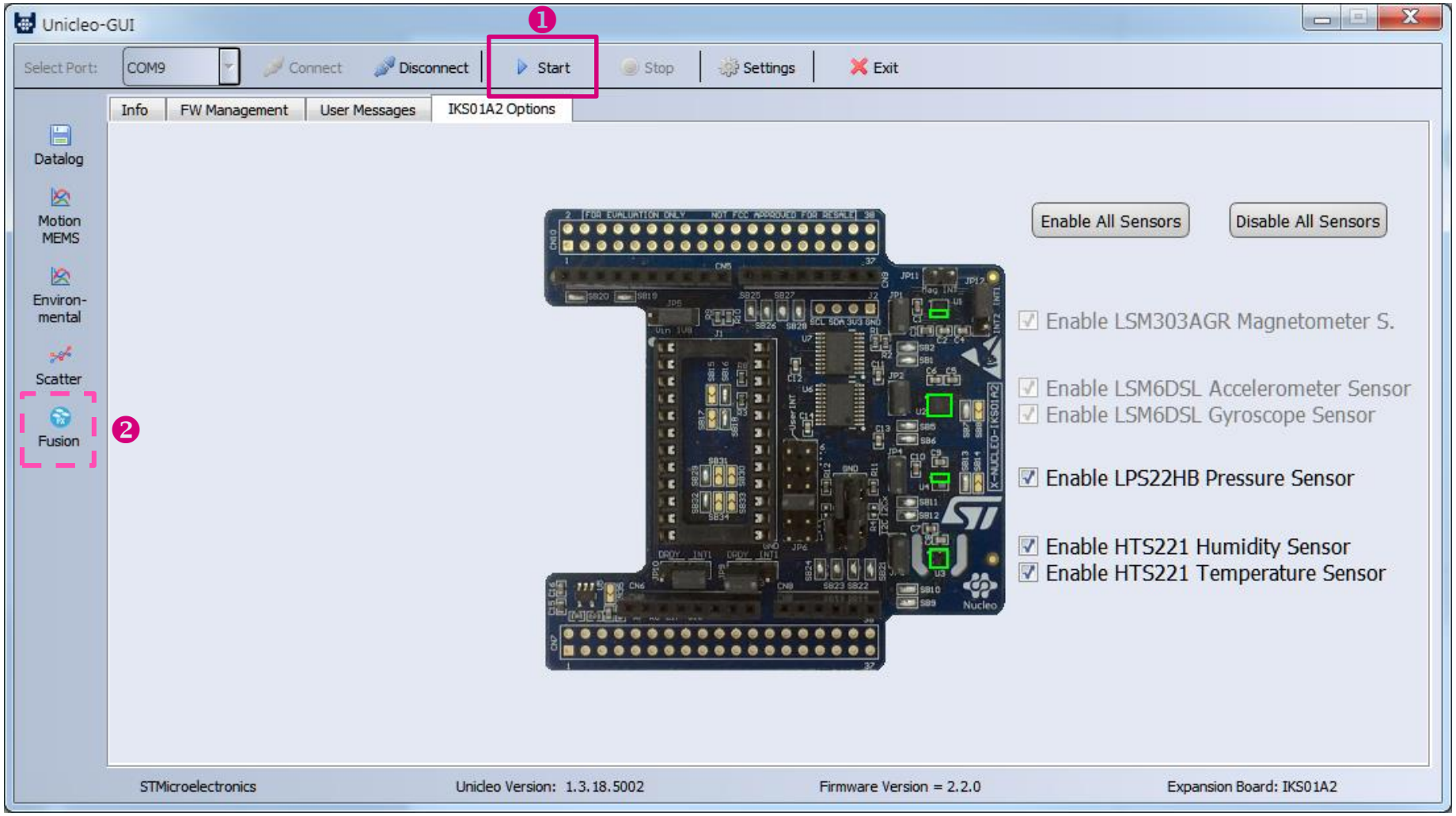


Launch Unicleo-GUI



Further Application Code Examples…