AGENDA

- What is an Inertial Measurement Unit (IMU) sensor
- Block diagram of 6-axis IMU sensor

- Accelerometer
  - Block diagram of Accelerometer
  - Capacitive sensing circuit

- Gyroscope
  - Block diagram of Gyroscope
  - Working principle of Gyroscope: Coriolis Effect
  - Tuning fork configuration and MEMS sensing unit

- IMU Technical parameters and general characterstics
  - Operating modes
  - Embedded functions
  - FIFO buffer configuration

- WSEN-ISDS IMU sensor for IoT/Industrial applications
- Conclusions

WHAT IS AN INERTIAL MEASUREMENT UNIT (IMU) SENSOR

An Inertial Measurement Unit (IMU) is a device that can measure and report **specific gravity/acceleration** and **angular rotational rate** of an object to which it is attached.

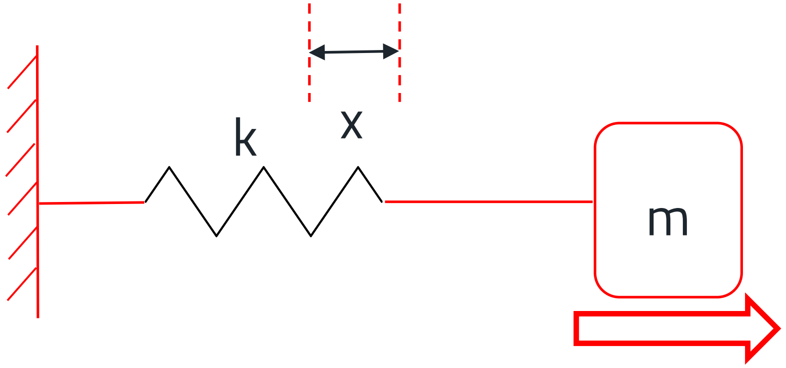
An IMU basically typically consists of:

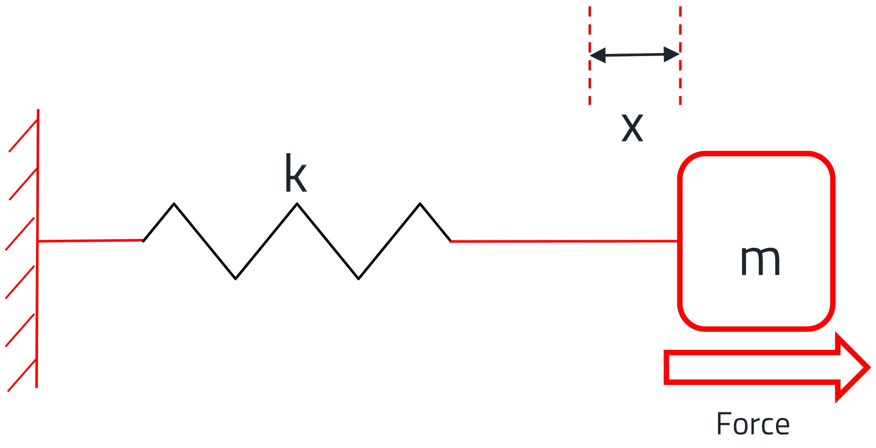
- **Accelerometers:** providing a measure of specific force/acceleration
- **Gyroscopes:** providing a measure of angular rate
- **Magnetometers (optional):** measurement of the magnetic field surrounding the system
- IMUs are generally composed of **3-axis accelerometer and a 3-axis gyroscope**, which would be considered a **6-axis IMU**.
- Additionally they can also include **a 3-axis magnetometer**, which would then considered as a **9-axis IMU.**

ACCELERATION

- Acceleration is the measurment of the **change in velocity, or speed by time.**
- An Accelerometer is an MEMS (Micro-Electro-Mechanical System) used to measure acceleration forces.
- MEMS capacitive element is employed inside the IC of an accelerometer

GENERAL PRINCIPAL OF ACCELERATION





Hooke's law

F = kx

F - Force due to spring tension

k - Spring constant

x - Extension of the spring

m - Mass of the Object

F = kx = ma

a = k/m (x)

Newton's second law

F = ma

F - Force applied on the object

m - Mass of the object

a - Acceleration

x - Displacement of the object

Acceleration ⟷ Displacement

DISPLACEMENT MEASUREMENT

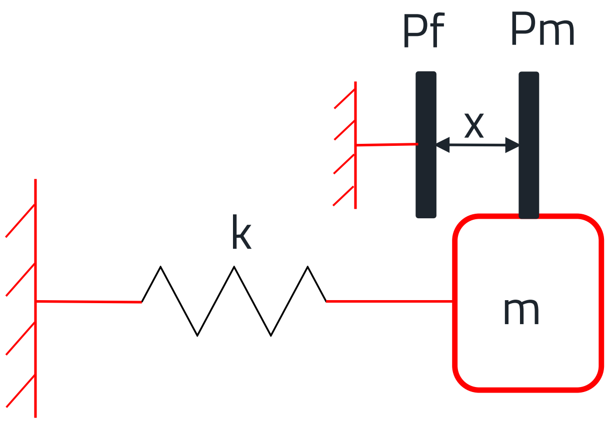
Different Technique:

Resistive

Inductive

Capacitive

Capacitive Technique:



$C = \varepsilon_0 A / (x)$

$a = k / m (x)$

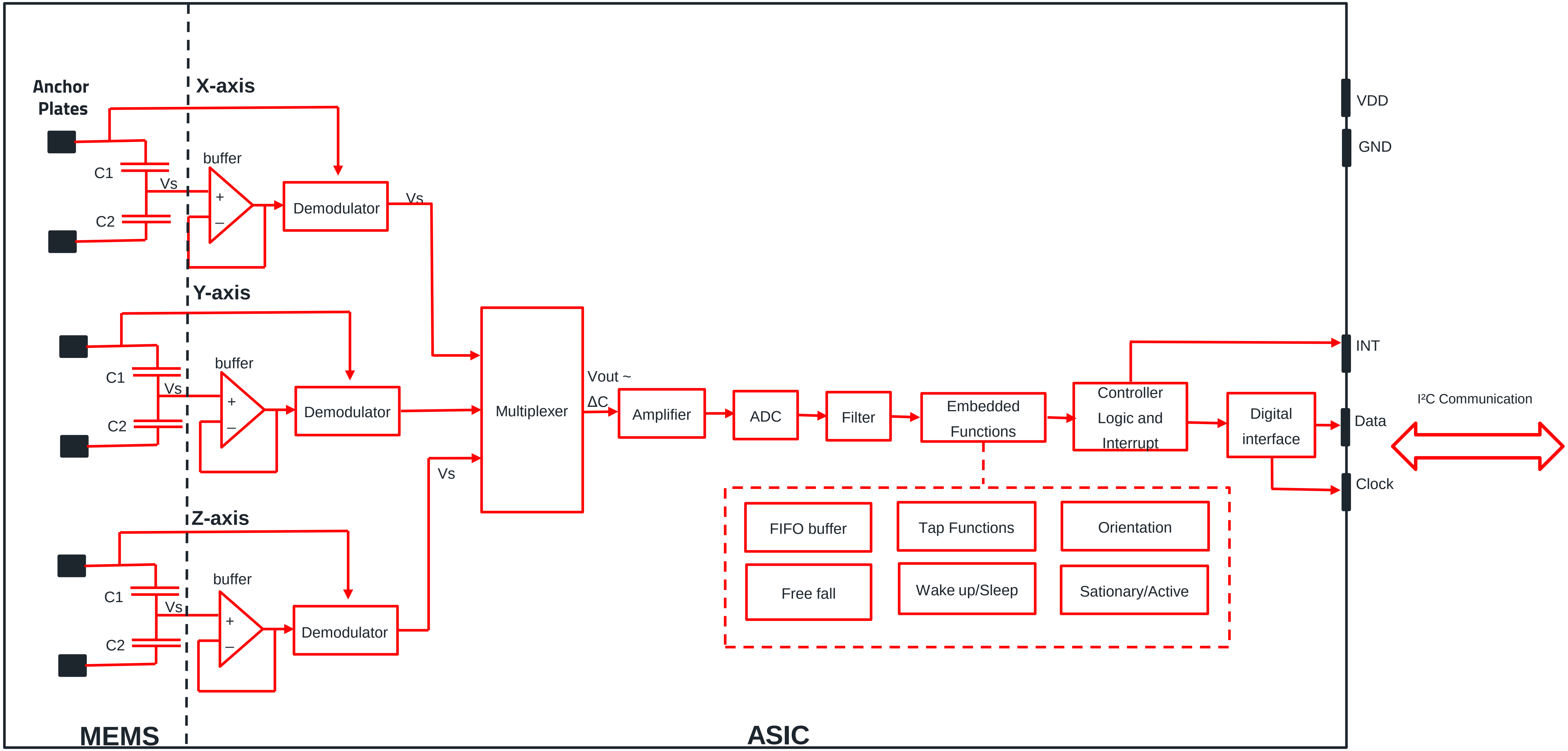
Displacement → Capacitance → Acceleration

Pm - Movable capacitor plate

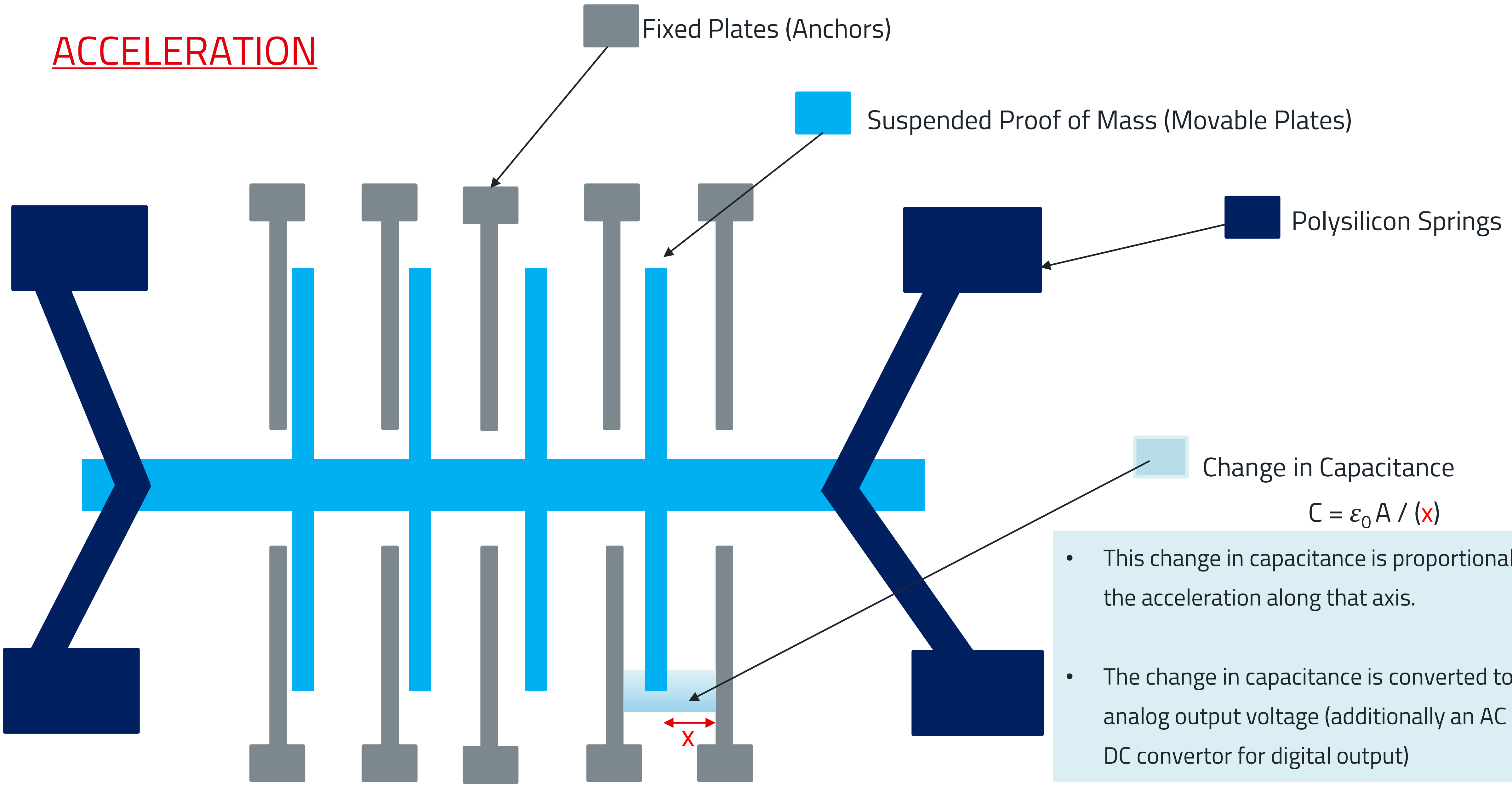
Pf - Fixed capacitor plate

x - Displacement

MEMS ACCELEROMETER SENSOR BLOCK DIAGRAM



ACCELERATION



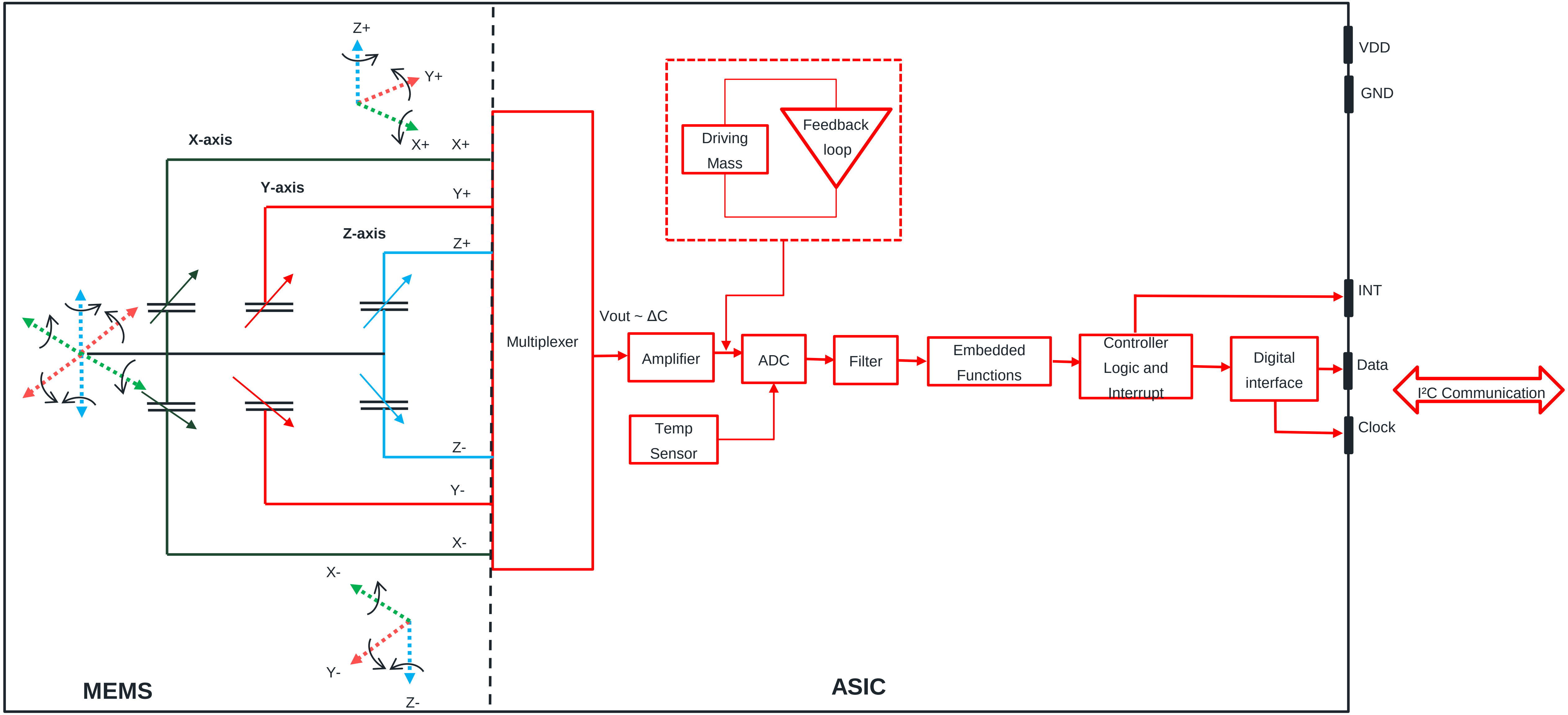
$$C = \varepsilon_0 A / (x)$$

- This change in capacitance is proportional to the acceleration along that axis.
- The change in capacitance is converted to an analog output voltage (additionally an AC to DC convertor for digital output)

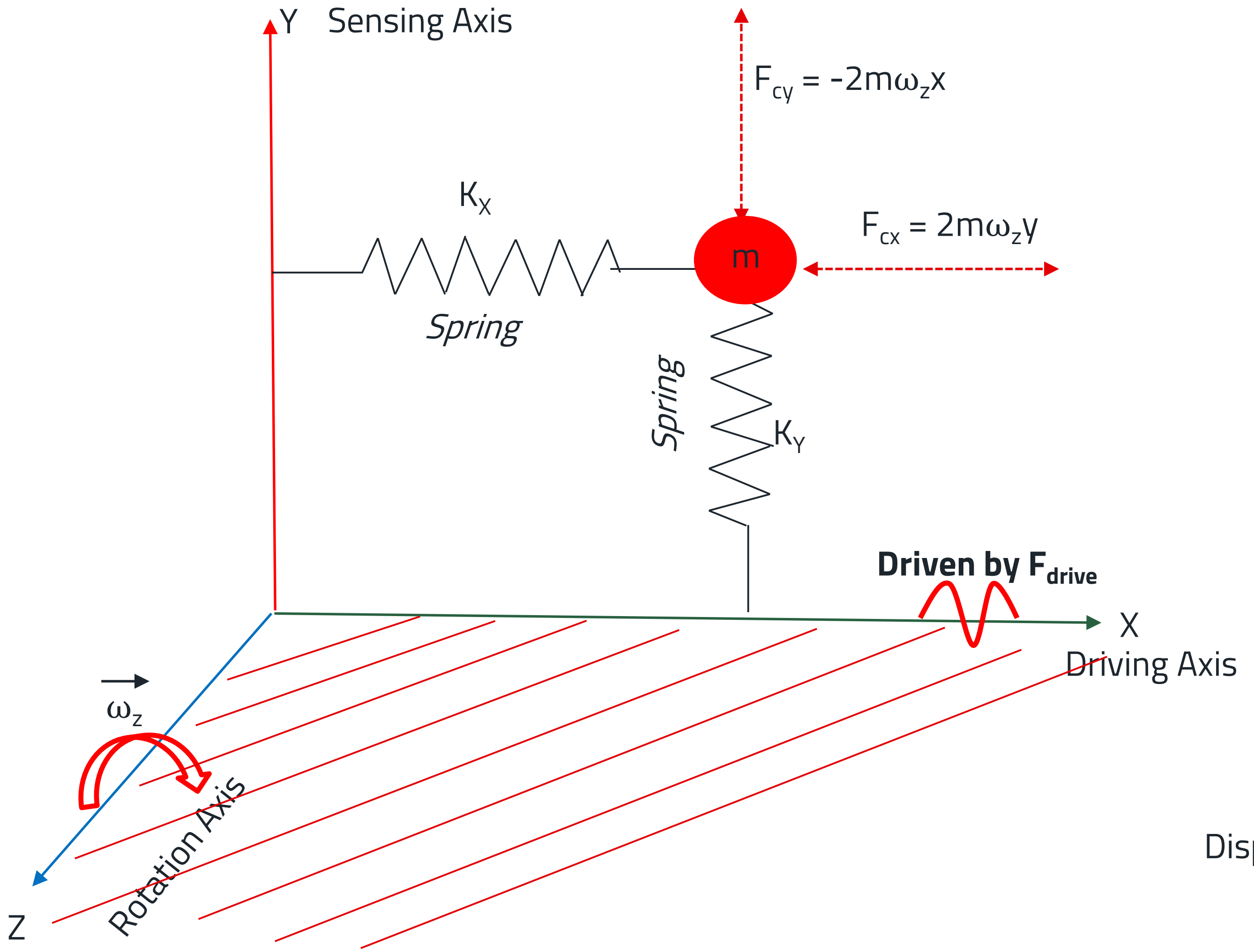
GYROSCOPES

- Gyroscope is a device used to for measuring **angular rotational rate and orientation**.
- Gyorscope adds an additional dimension to the information supplied by the accelerometer by tracking rotation or twist.
- Together Acceleration and Gyro is called as IMU sensor is an electronic device that measures and reports a body´s specfic force, angular rate and orientation of the body.

MEMS GYROSCOPE SENSOR BLOCK DIAGRAM



VIBRATORY SPRING-MASS GYROSCOPE SYSTEM



- m is the mass in X-Y plane
- K_x (K_y) - spring-constants
- X represents the driving axis
- Y represents the sensing axis
- Z represents the rotation axis
- F_{drive} → Ref driving signal (freq and amplitude)

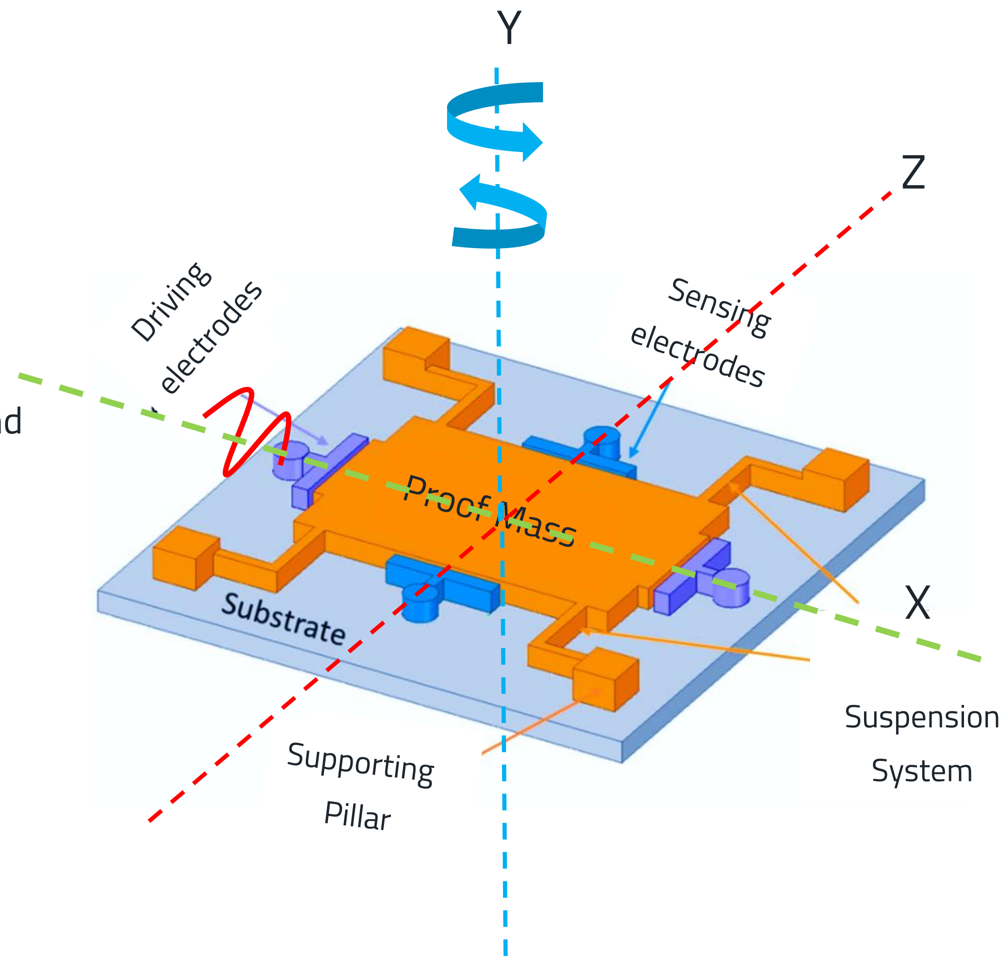
ω_z >0 (angular rate applied along Z axis)

- F_{cx} and F_{cy} →Coriolis force appear in X & Y axis

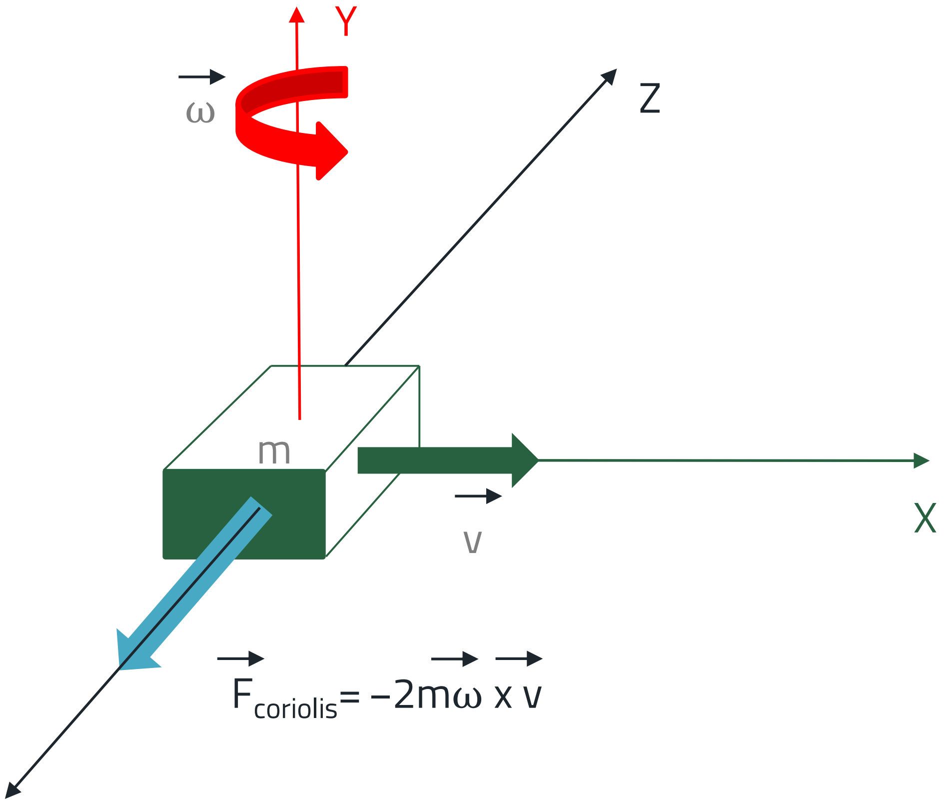
Displacment in Y (Sensing axis) due to force F_{cy}→ propotional to ω_z

GYROSCOPE MEMS IMPLEMENTATION

- A Proof mass (m) placed above the silicon substrate.
- Driving, sensing electrodes, and a suspension support beam system with four fixed support pillars.
- The driving system provides an oscillation (X-axis) with a certain amplitude and frequency.
- The **proof mass becomes an oscillator**
- The same proof mass upon external rotation (Y-axis) changes its oscillation movement to the orthogonal direction (Z-axis)
- The sensing electrodes (Z-axis) detect the Coriolis force that is produced by the mixture of driving momentum and external rotation.



CORIOLIS EFFECT



$\vec{F}_{coriolis} = -2m\vec{\omega} \times \vec{v}$

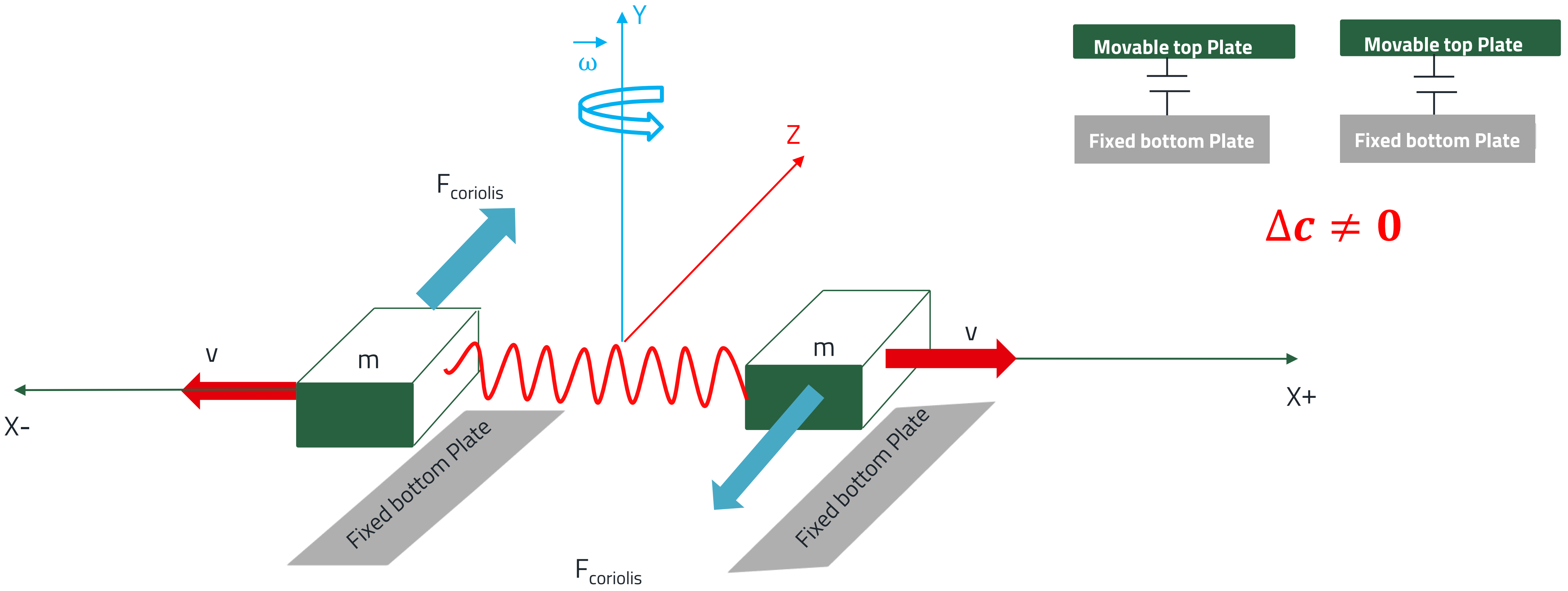
- When a mass (m) moves in a specific direction with a velocity (v)

and

- External angular rate (ω) is applied (Red arrow)
- Coriolis Effect generates a force ($F_{coriolis}$) that causes the mass to move perpendicularly

The value of this displacement is directly related to the angular rate applied.

GYROSCOPE: TUNING FORK CONFIGURATION (MEMS SCENARIO)

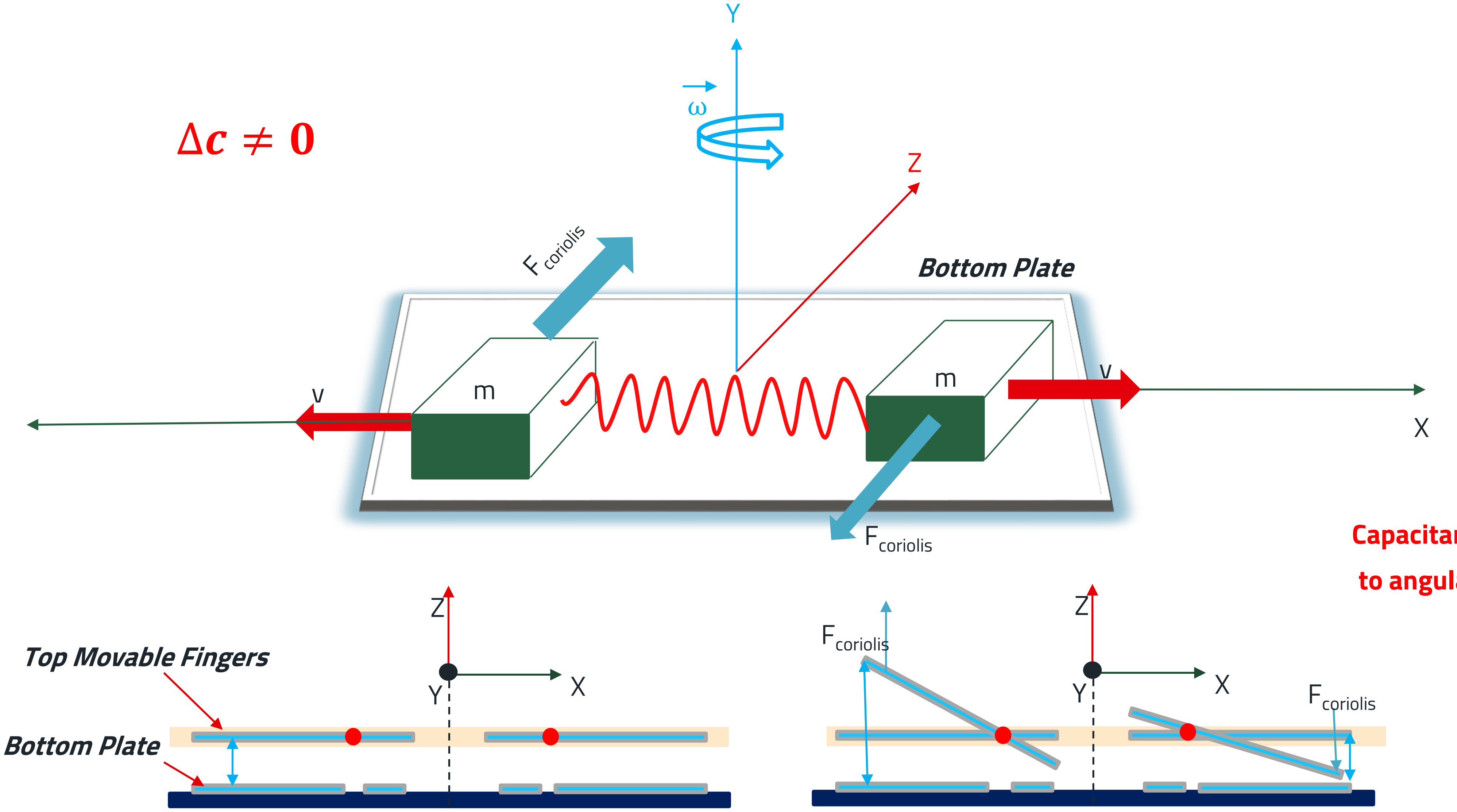


$$\Delta c \neq 0$$

- Two proof of masses (m) moves in opposite direction at a constant frequency.
- When an angular rate is applied, the Coriolis effect produced by each mass is in opposite directions.
- Measuring this change in capacitance, the angular rate can be calculated.

TUNING FORK CONFIGURATION:

$\Delta c \neq 0$



No angular velocity applied

Angular velocity applied

Capacitance Variance (parallel plate) due to angular rotation is read by electronic interface

OPERATING MODES

Operating configurations:

- Only accelerometer active and gyroscope in Power-Down
- Only gyroscope active and accelerometer in Power-Down
- Both accelerometer and gyroscope active with independent output data rate (ODR).

Operating modes: The accelerometer and the gyroscope can be independently configured in four different power modes:

- Power Down
- Low-Power
- Normal
- High-Performance mode

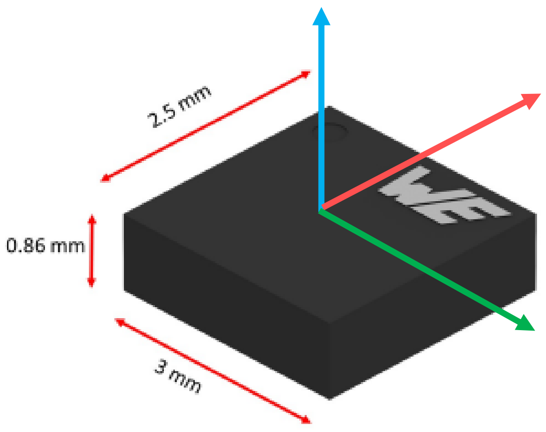
Additionally, the gyroscope sensor can also be set in Sleep mode to reduce its power consumption.

POWER CONSUMPTION AND NOISE

Power Consumption Mode	Output Data Rate ODR (Hz)	Current Consumption (µA)
Combo (Gyro+Acc) High power mode	1600	690
Combo (Gyro+Acc) Normal power mode	208	500
Combo (Gyro+Acc) Low power mode	53	350
Accelerometer High power mode	<1600	180
	>1600	190
Accelerometer Normal power mode	208	85
Accelerometer Low power mode	52	25
	12.5	9
	1.6	4.5

	Test Condition	Value	Units
Acceleration Noise Density	FS = ±2 g	75	µg/√Hz
	FS = ±4 g	89	µg/√Hz
	FS = ±8 g	90	µg/√Hz
	FS = ±16 g	130	µg/√Hz
Gyro Noise Density	High -performance mode	3.8	mdps/√Hz

WSEN-ISDS: IMU SENSOR TECHNICAL PARAMETERS



Specifications

- Dimension - 2.5 mm x 3.0 mm x 0.86 mm (14pin) LGA package
- Acceleration Range: ±2g,/±4g,/±8g,/±16g
- Gyroscope Range: ±250 dps, ±500 dps, ± 1000 dps, ±2000 dps
- Resolution – 16 bits
- Sensitivity – 3%
- Current Consumption - HP mode: 690µA, NP mode: 370 µA, LP mode: 280 µA
- Low Noise Density – 75 µg√Hz
- Output Data Rate - upto 6.6KHz, BW_{acc} – 1400 Hz, BW_{Gyro} – 937 Hz
- Operating Temperature Range: -40°C to +85°C

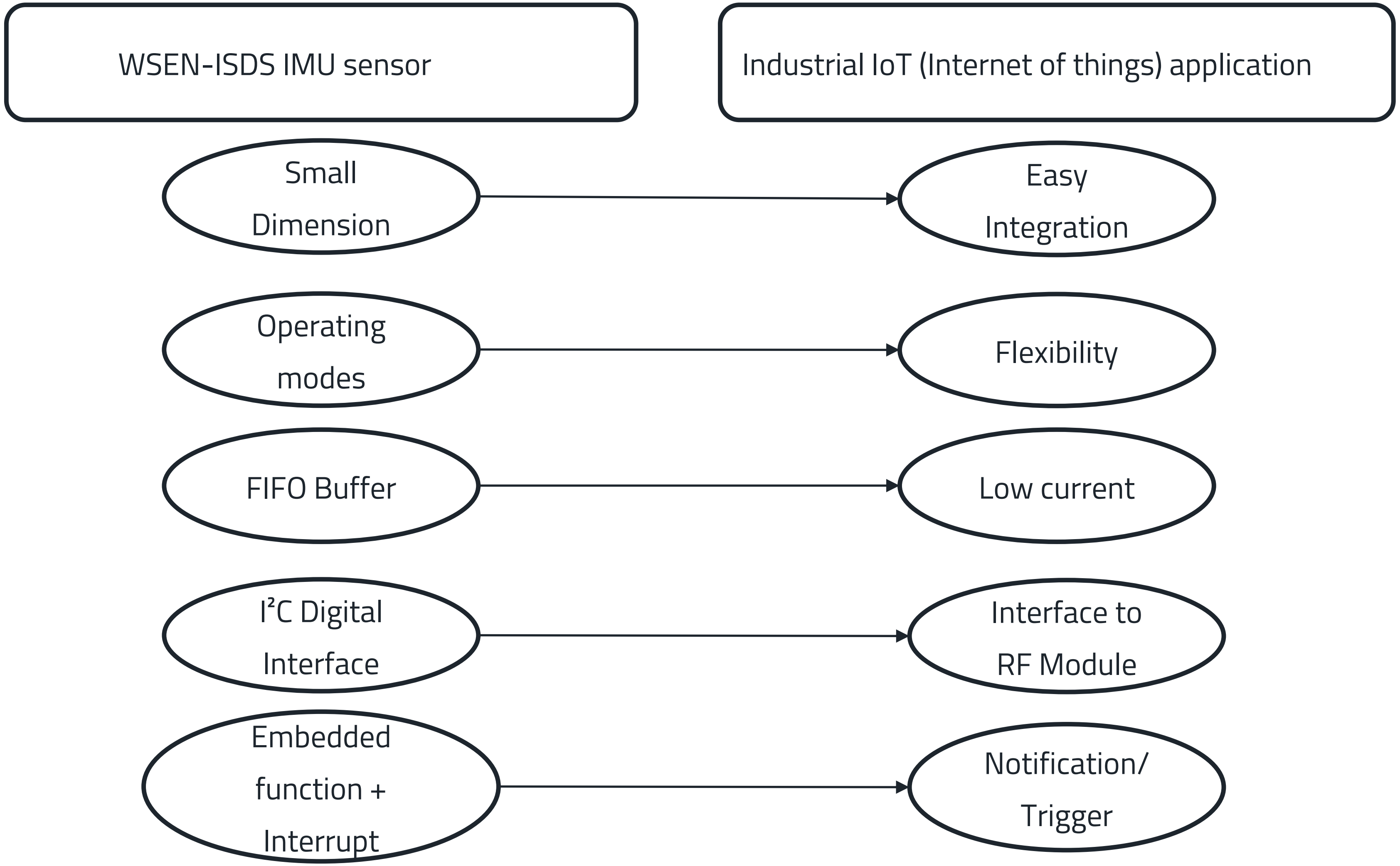
Application

- Industrial 4.0 and IoT connected devices
- Industry tools and factory equipment
- Antenna and platform stabilization
- Localization and navigation
- Robotics, drones and automation

Special Features

- Operation Mode – High Performance, Normal, Low Power
- 4 kbyte FIFO – flexible data handling
- 2 Independent Interrupts pins
- I^2C and SPI bus interface
- Embedded functions: freefall, wake-up, tap, activity, motion, orientation: 6D/4D, Tilt sensing

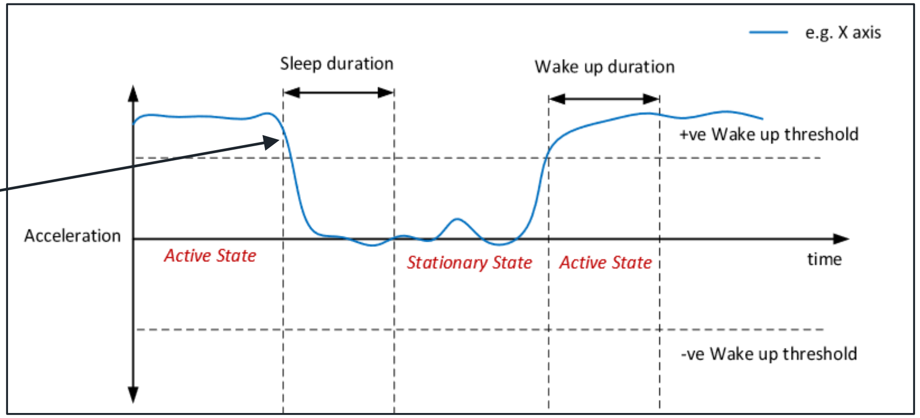
HOW WSEN-ISDS IS SUITABLE FOR INDUSTRIAL IOT APPLICATIONS



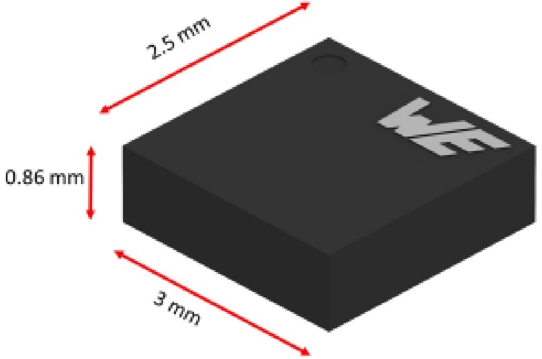
WSEN-ISDS SENSOR: EMBEDDED FUNCTIONS

- Active/Inactive
- Sleep and wake up
- Free fall
- Tap functions
- Orientation

Active/Inactive

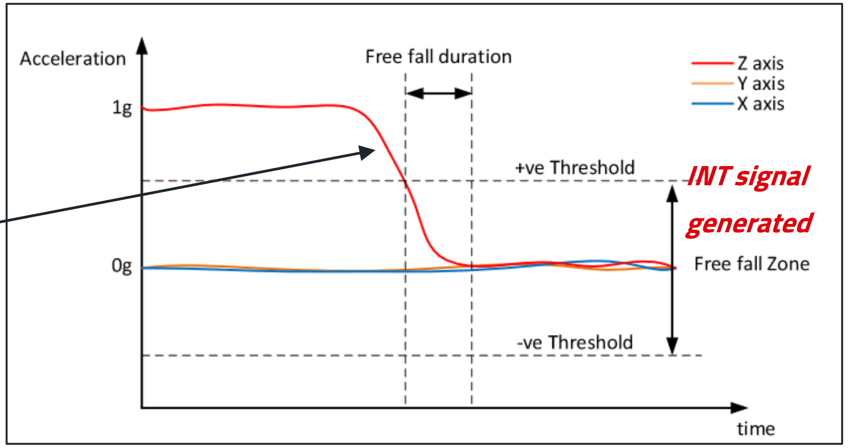


Activity/Inactivity recognition function allows reducing system power consumption (suitable for IoT applications)



WK interrupt signal is generated if filtered data exceed the configured threshold

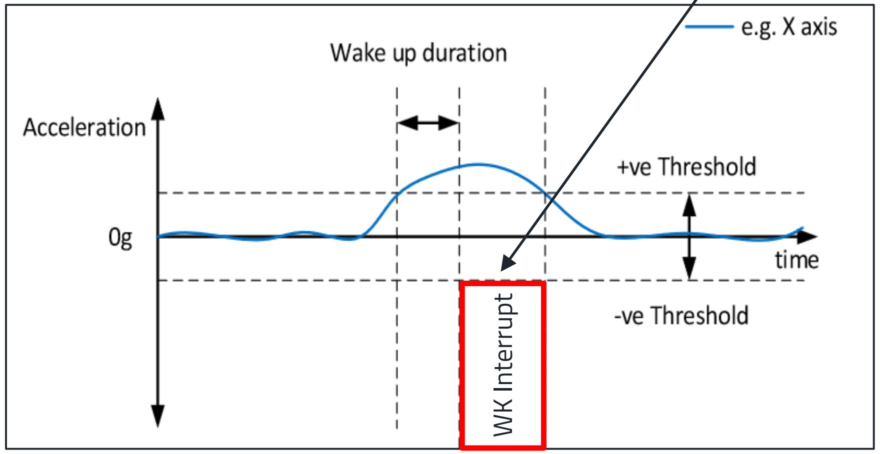
Free Fall Interrupt



INT signal generated

Acceleration measured along all the axes goes to zero

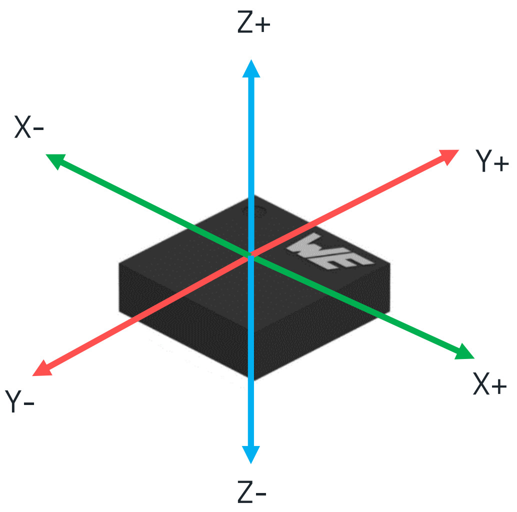
Sleep Wake up Interrupt

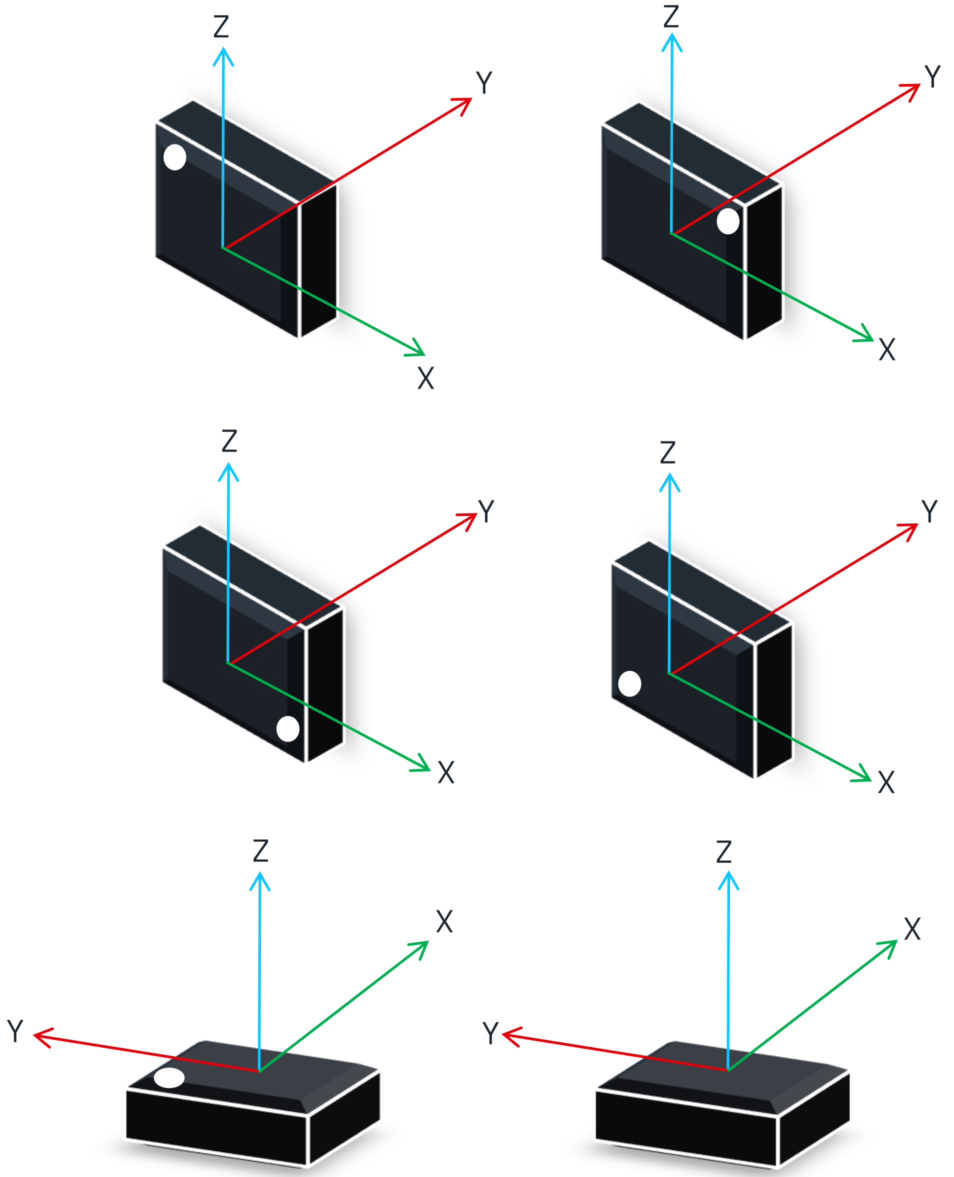


WSEN-ISDS SENSOR: EMBEDDED FUNCTIONS

6D/4D Orientation Detection

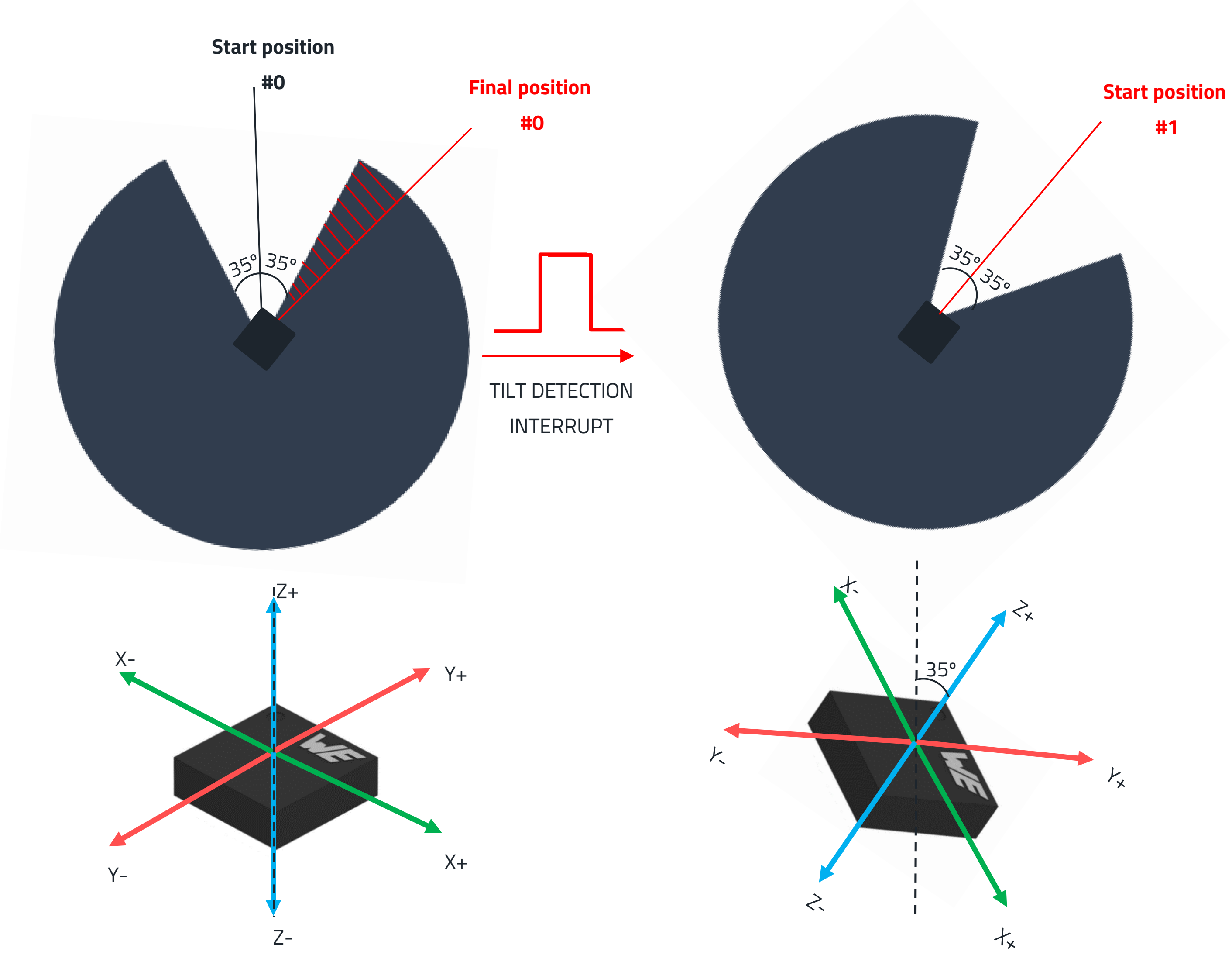
- Six orientations of the device in space can be detected.
- 4D direction function is a subset of the 6D function.
- Image processing – orientation & amplitude of digital camera





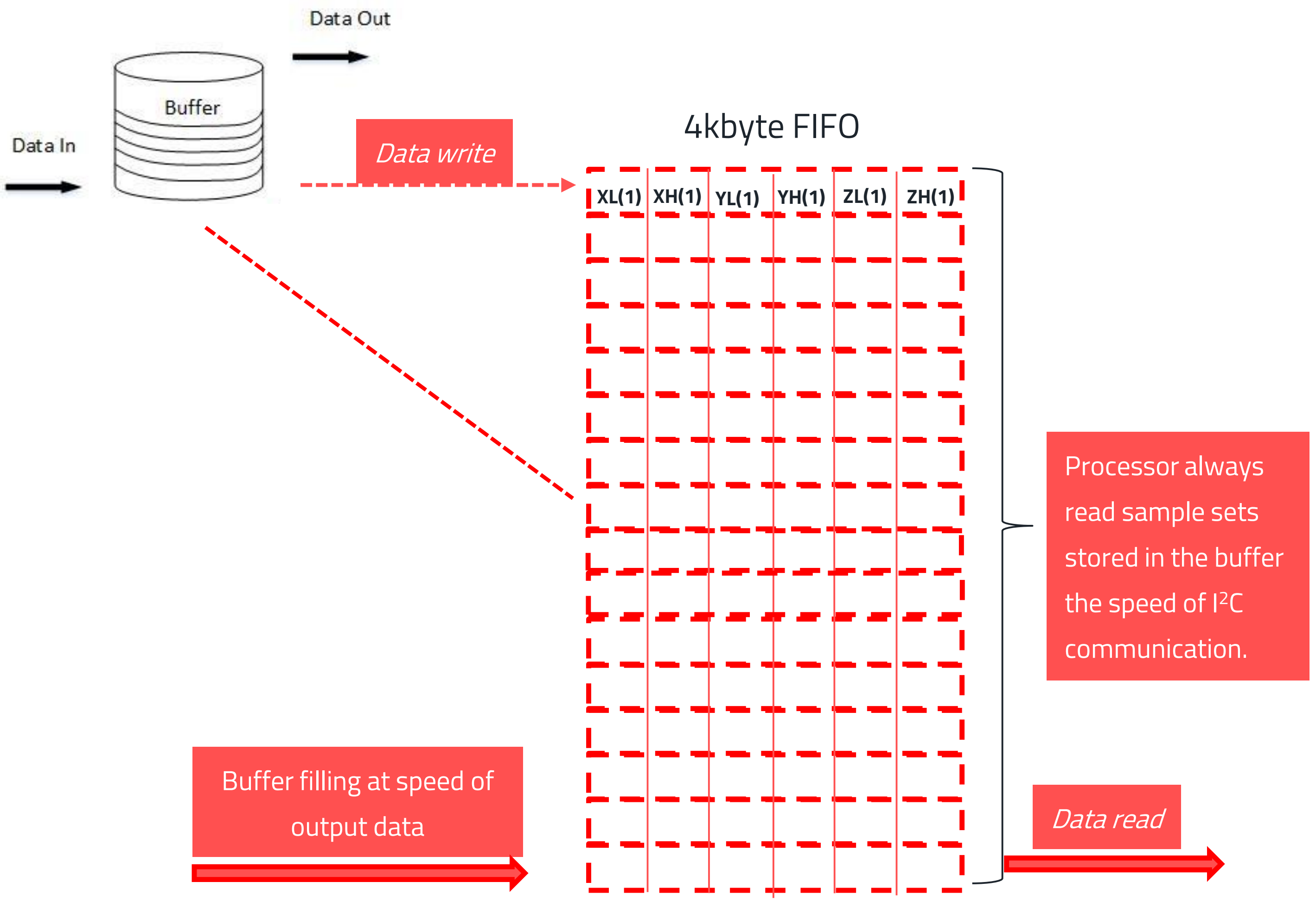
WSEN-ISDS SENSOR: EMBEDDED FUNCTIONS

Relative Tilt:



- An interrupt is generated when the device is tilted by an angle > 35°
- Seq0 → Seq1 (Start position changes w.r.t previous Seq end position)

WSEN-ISDS SENSOR: FIFO BUFFER

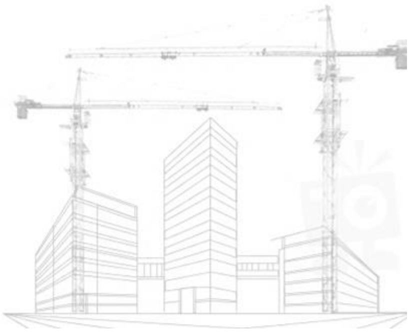


Smarter power management

- Less/no communication with Microcontroller

- First in First Out (FIFO)
- Reduce communication between sensor and MCU
- 4k bytes to store the output values
- Different modes of operation
  - Bypass mode → No Buffer fill
  - Continuous mode → Replace old with new
  - Bypass to continuous (Record an event)
  - Continuous to bypass (after event)

INDUSTRIAL MARKET APPLICATIONS



Structural Monitoring

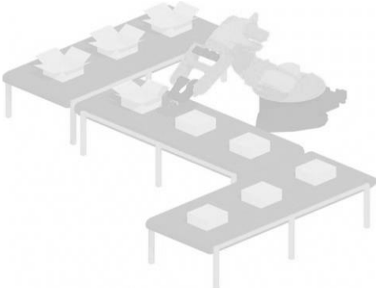
Buildings, Bridges, Railways

Rotation Equipment /Parts

Robots

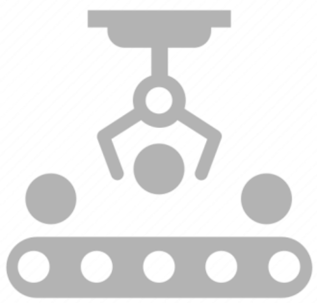
Consumer Industrial (HVAC)

Elevators, escalators



Industrial Logistics

Earth Movers and Cranes



Pick and Place (P&P)

machines

Predictive maintenance

and

condition monitoring

CONCLUSION

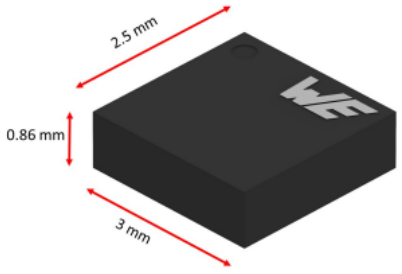
Best suitable for IIoT application

Low current <0.69 mA

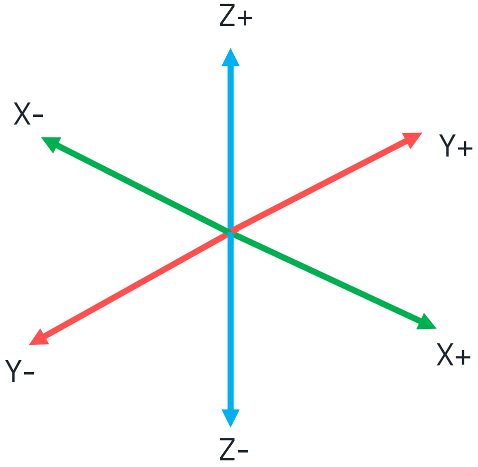
FIFO Buffer 4k bytes

Embedded Smart Features

I^2C Interface



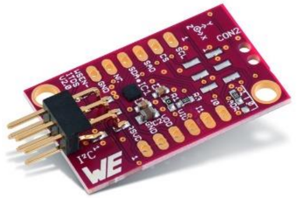
MEMS 6-AXIS IMU Sensor



Accelerate your project and ideas

Evaluation Board

Sensor driver



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Resolution: ±3%

Smart FIFO up to 4 kbyte

BW Accelerometer : 1400kHz

BW Gyroscope : 937 KhZ

Output Data Rate: 6.66 kHz

Selectable full scale for acceleration: ±2g, ±4g, ±8g, ± 16g

Selectable full scale for Gyroscope:

±125/±250/±500/±1000/±2000 dps

FAQ

- Do we have SDK files available in the GitHub ?
- How is the Accelerometer sensitivity measured ?
- What is the purpose of internal Temperature sensor ?
- Main difference between the ISDS and ITDS Accelerometer ?
- Is the aging of the sensors taken into account ?


Thank you