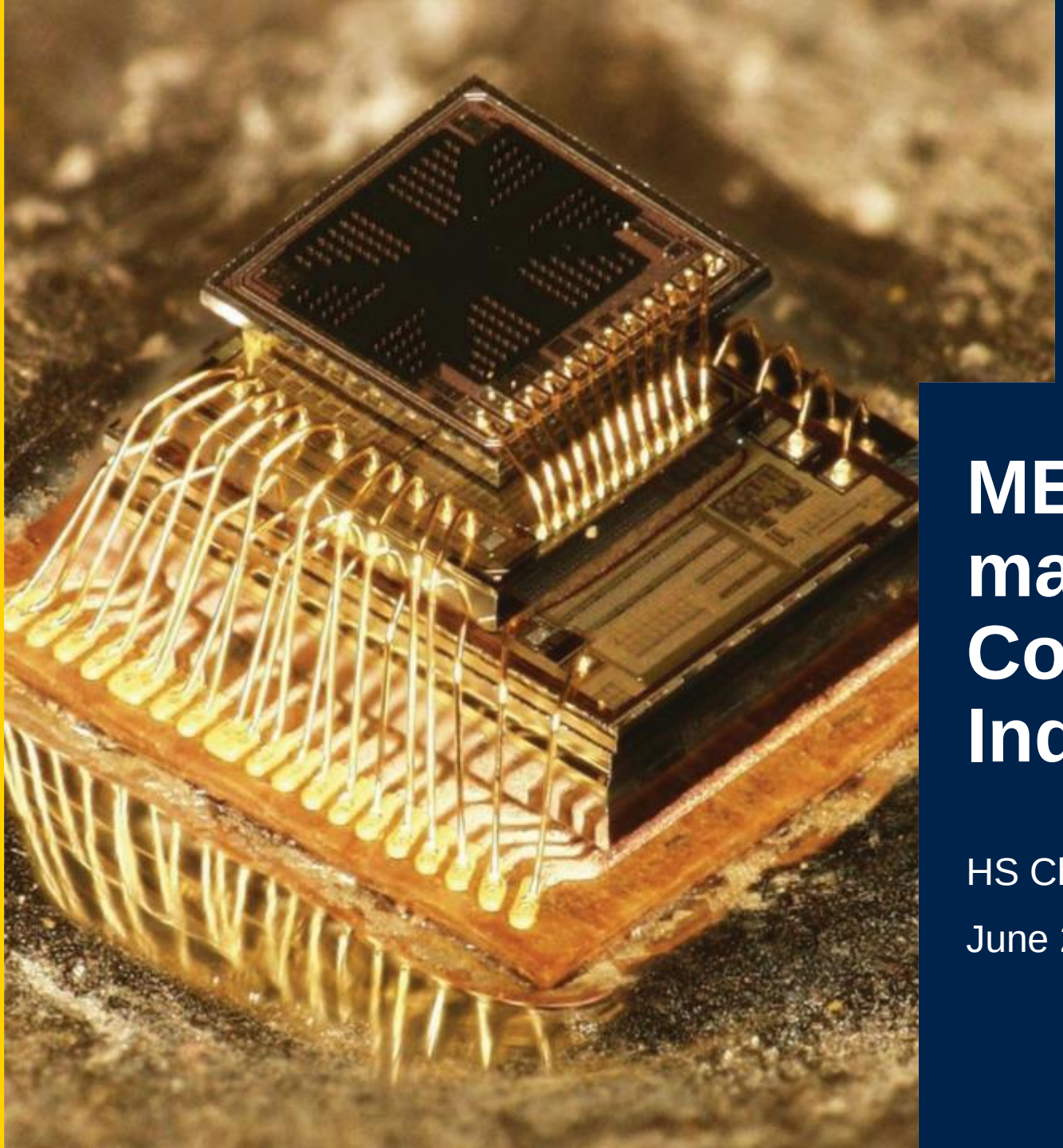

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MEMS sensors in motor machinery applications Condition monitoring for Industry 4.0

HS Chen

June 2023

ST Milan - The home of MEMS

~600
People

>400
Patents

>150
Product & SW libraries

x2
Dual fab source

>6Mu/d
Best-in-class service

27B
Shipped sensors

23 years & 27 billion MEMS at ST

2000
Entering the consumer market

2014
Automotive qualified MEMS sensors

2015
MEMS sensors for industrial applications

2023
Ongoing MEMS R&D and new developments

Sensors

Actuators

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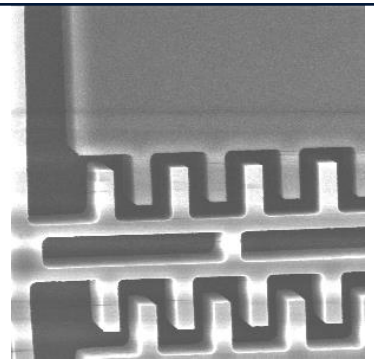
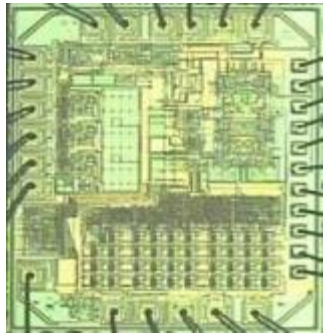
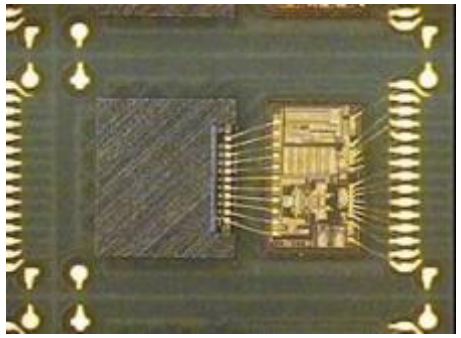
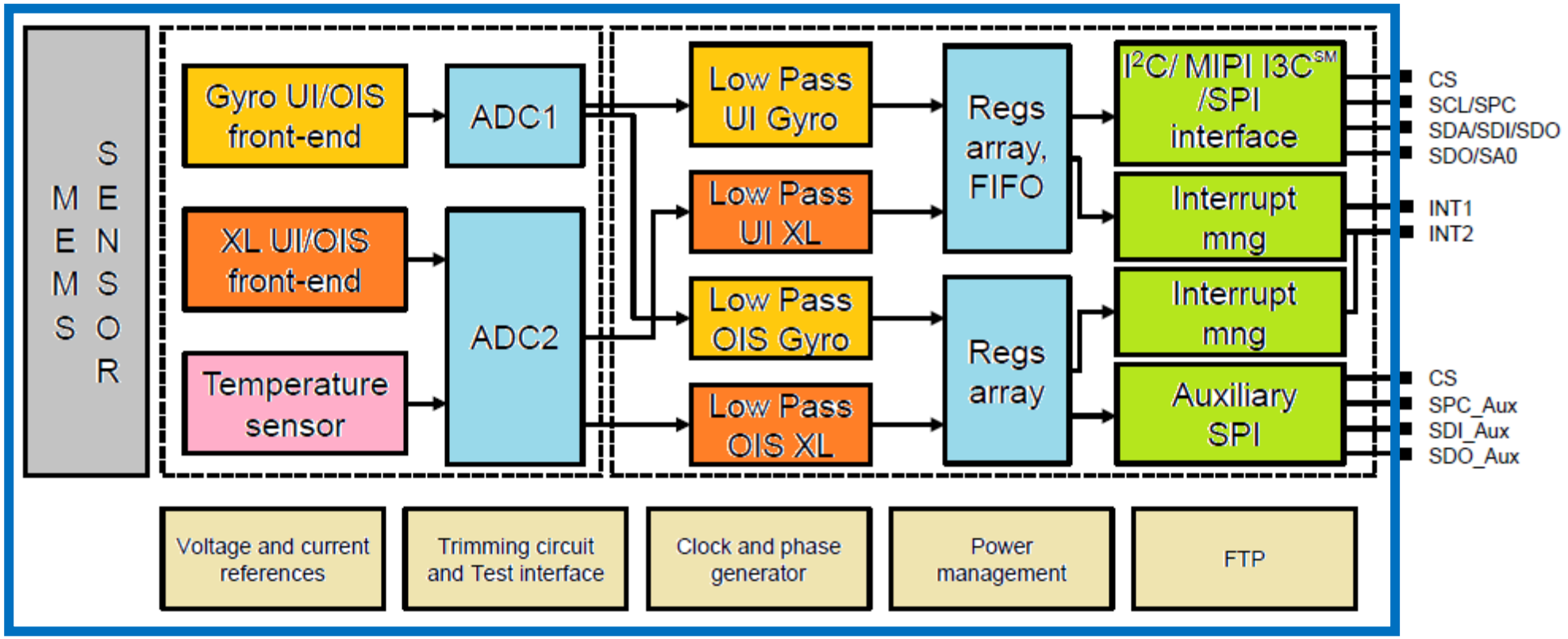
Device block example







- MEMS is Micro ElectroMechanical Systems
- MEMS contain movable 3D structure
- Structure move according to external displacement



Brief of ST MEMS sensors

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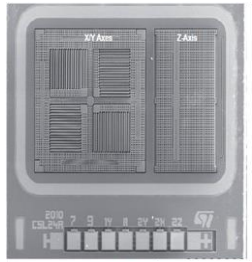
Accelerometer
Linear acceleration measurement

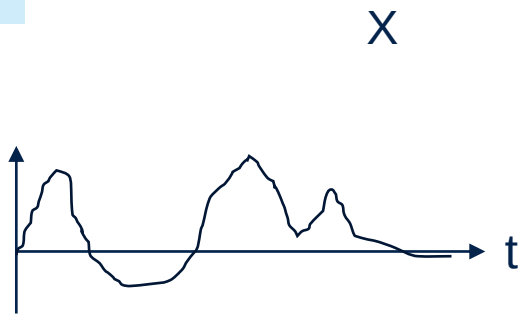


1. Accelerometer can sense linear acceleration.
2. Linear acceleration can be expressed in two forms:

$$A = \frac{V_2 - V_1}{\Delta t}$$

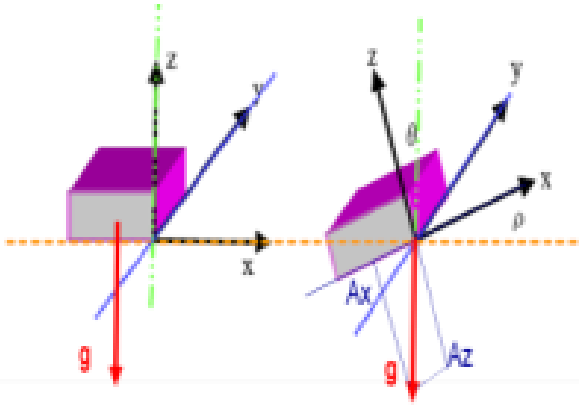
and

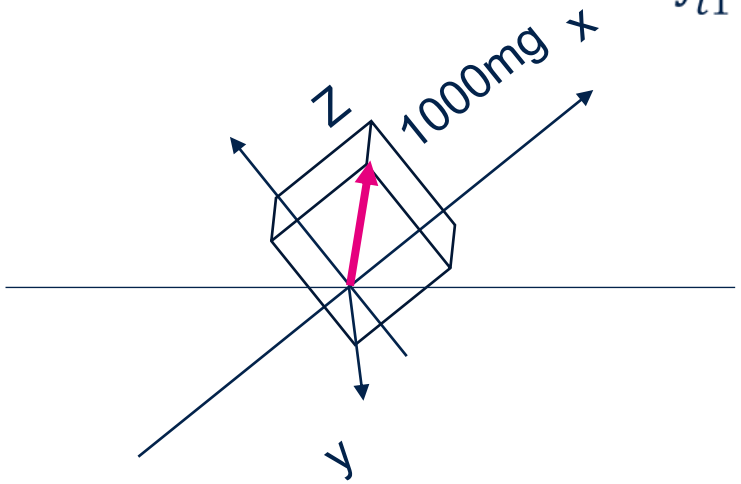
$$A = \frac{F}{m}$$



$$v(t) = \int_{t1}^{t2} A(t)dt$$

$$d = \int_{t1}^{t2} v(t)dt$$





3. Output from sensor is acceleration and always expressed in mg or m/s^2
4. It can be used to sense the linear acceleration (m/s^2), tilt, shocks, freefall, orientation detection, vibrations, etc.

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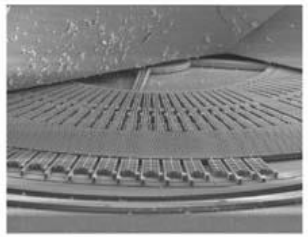
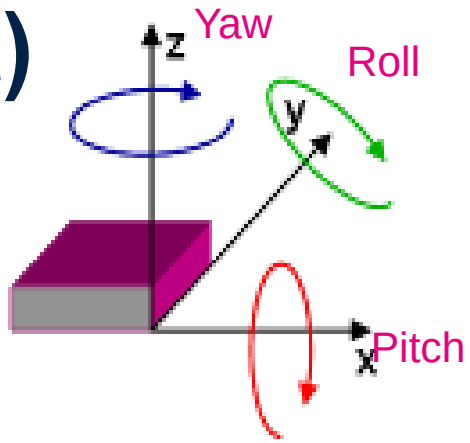
Gyroscope
Rotation speed measurement



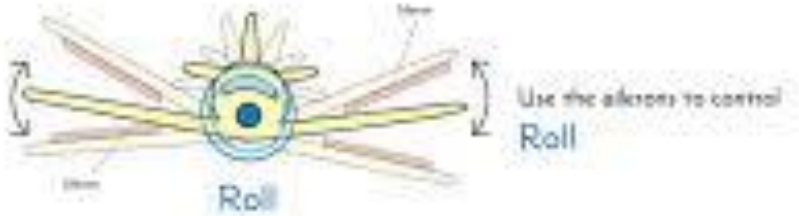
1. Gyroscope can sense the rotation speed or angular rate.
2. Angular rate can be expressed in:

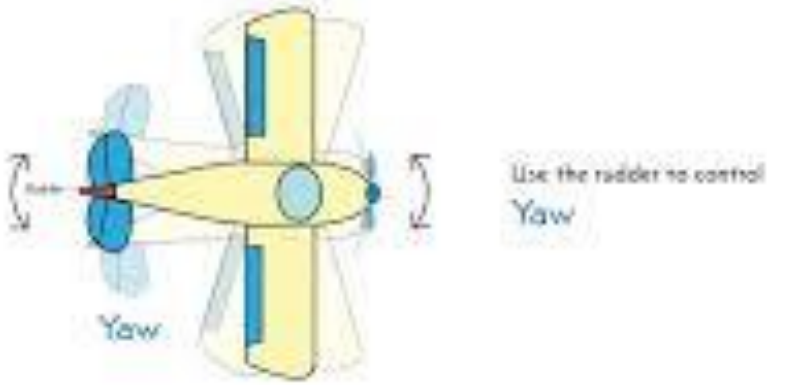
$$\theta = \int_{t1}^{t2} \omega(t)dt$$

ω(t)



3. Output from gyroscope is in mdps (m° /s).
4. Gyroscope can be used to measure the angular rate, number of revolutions (spin), rotation of mechanical part etc.





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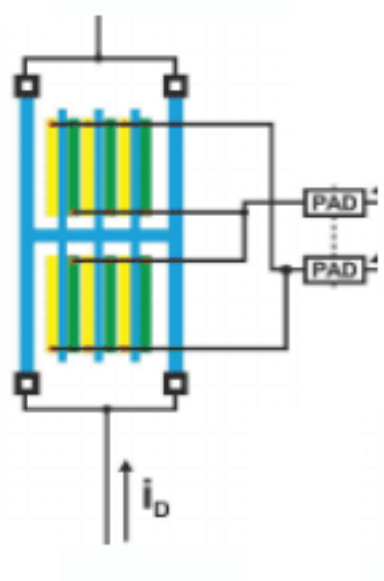
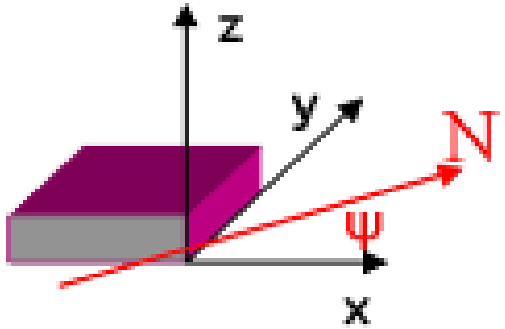
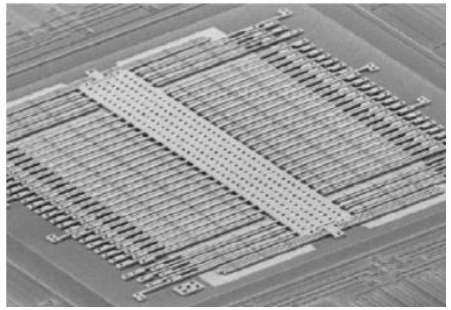
Magnetometer
Magnetic field measurement

1. Magnetometer can sense **magnetic field**
2. Output of magnetic B is expressed in mGS



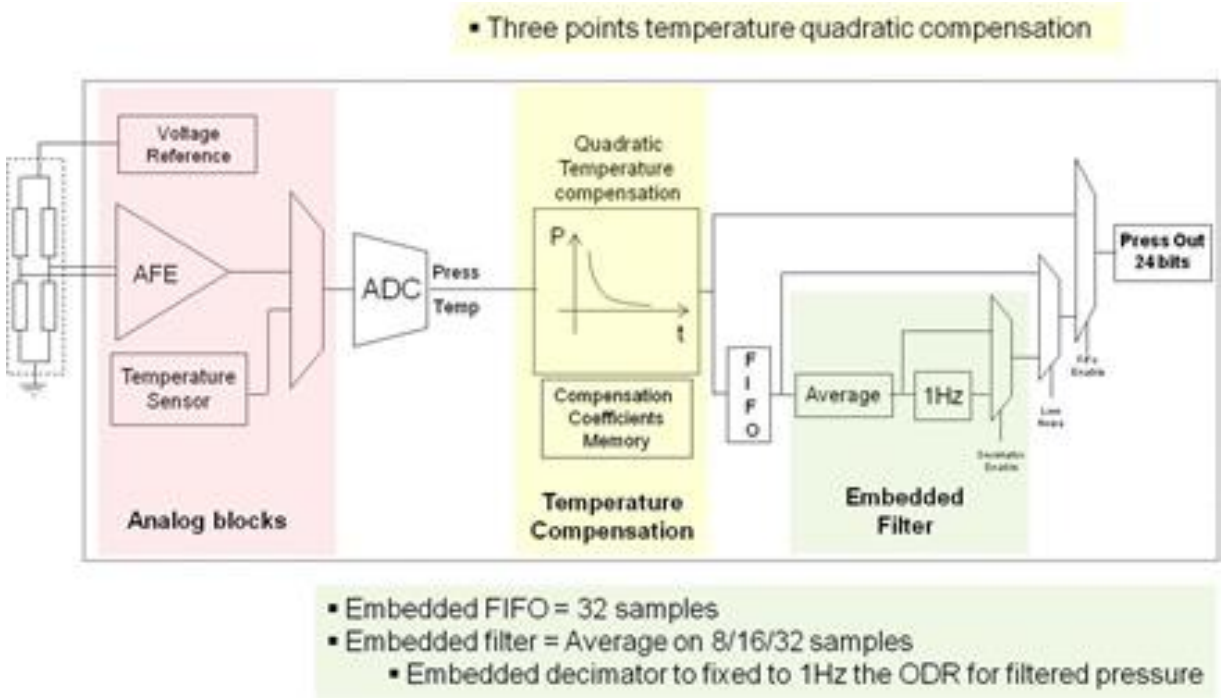


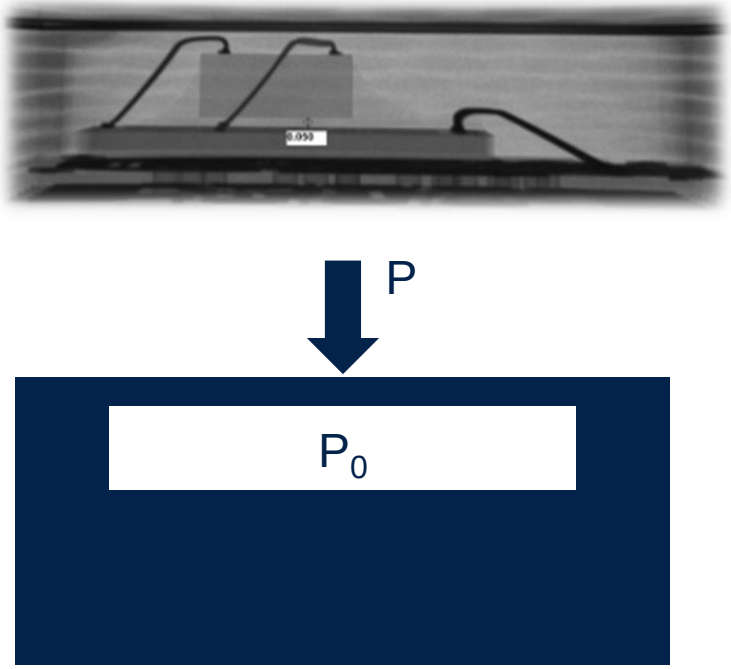


3. Magnetometer can sense the magnetic field (gauss) strength, which can be used to compute the absolute pointing direction with reference to geographical North

Pressure sensor
Ambient pressure measurement

1. Pressure sensor can measure ambient pressure which can be air or liquid
2. Output of pressure sensor is expressed in mBar or hPa





3. Pressure sensor can be used to monitor air speed, altitude, and atmospheric pressure

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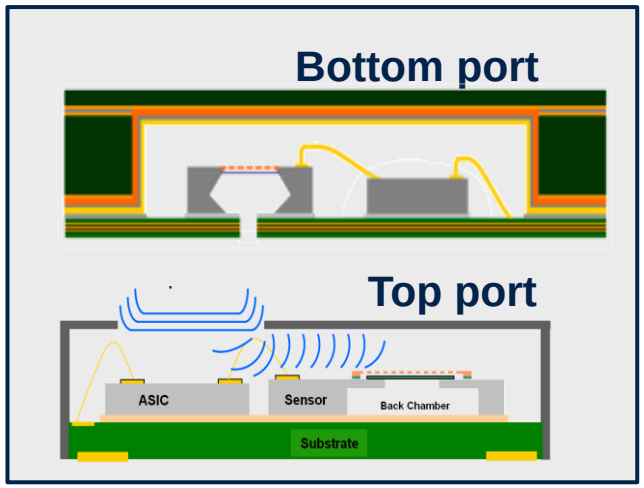
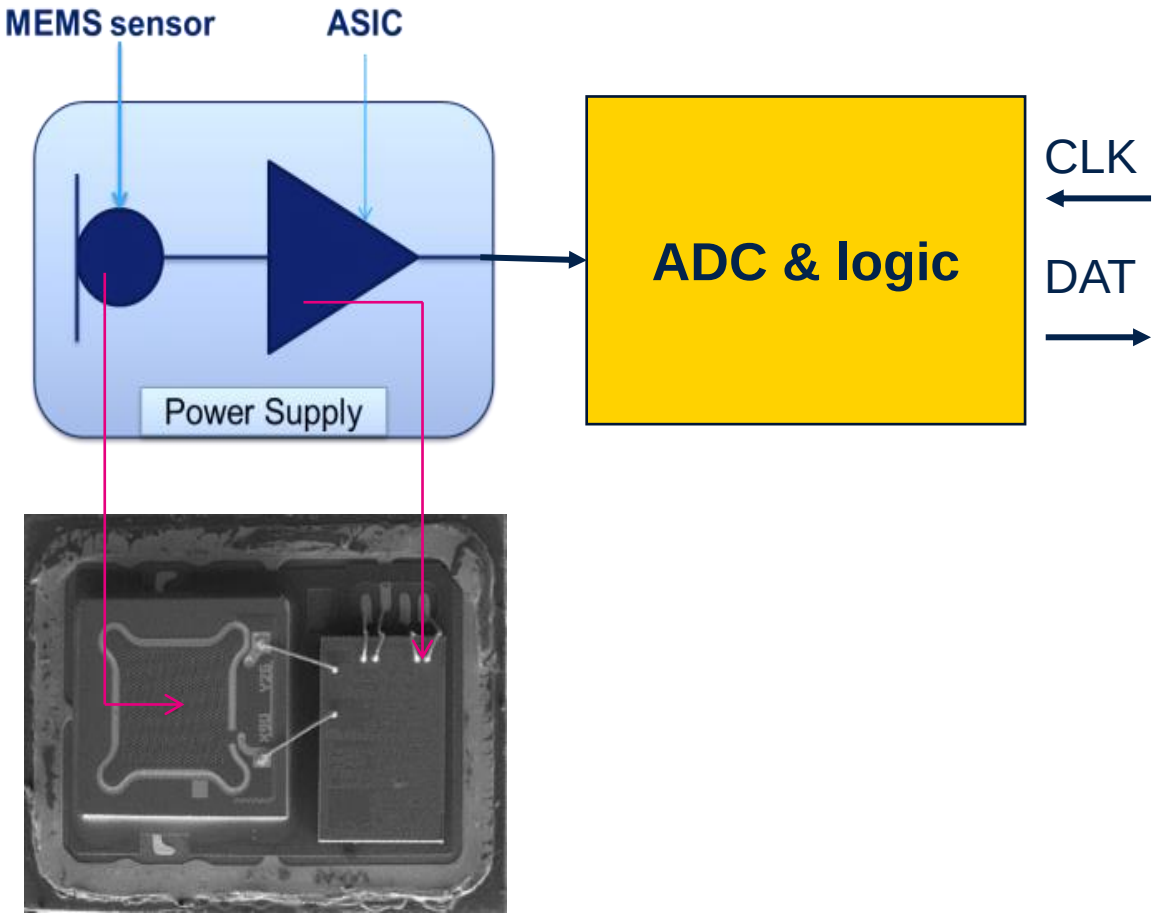
MEMS microphone
Acoustic measurement

1. MEMS microphone can **pick up voice from environment**
2. Sound pressure is expressed in dBSPL in PDM for digital MIC or mV for analog MIC



- Small form factor
- Allowed reflow
- Better temperature coefficiency
- Better part-part matching



ST MEMS sensors are everywhere
Applications

Spaceship

Transformer. Vibration

Predictive maintenance

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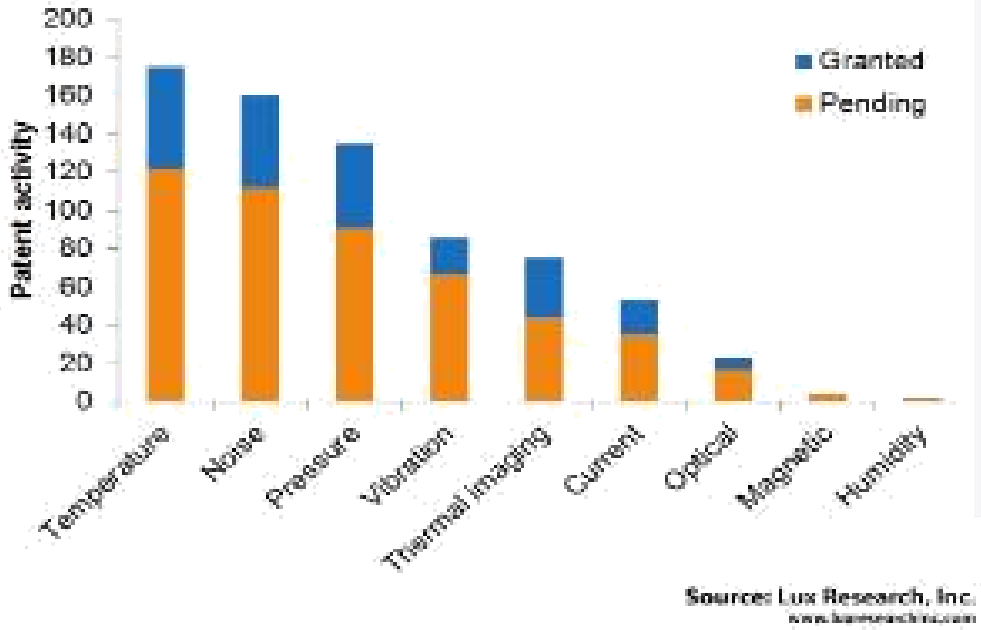
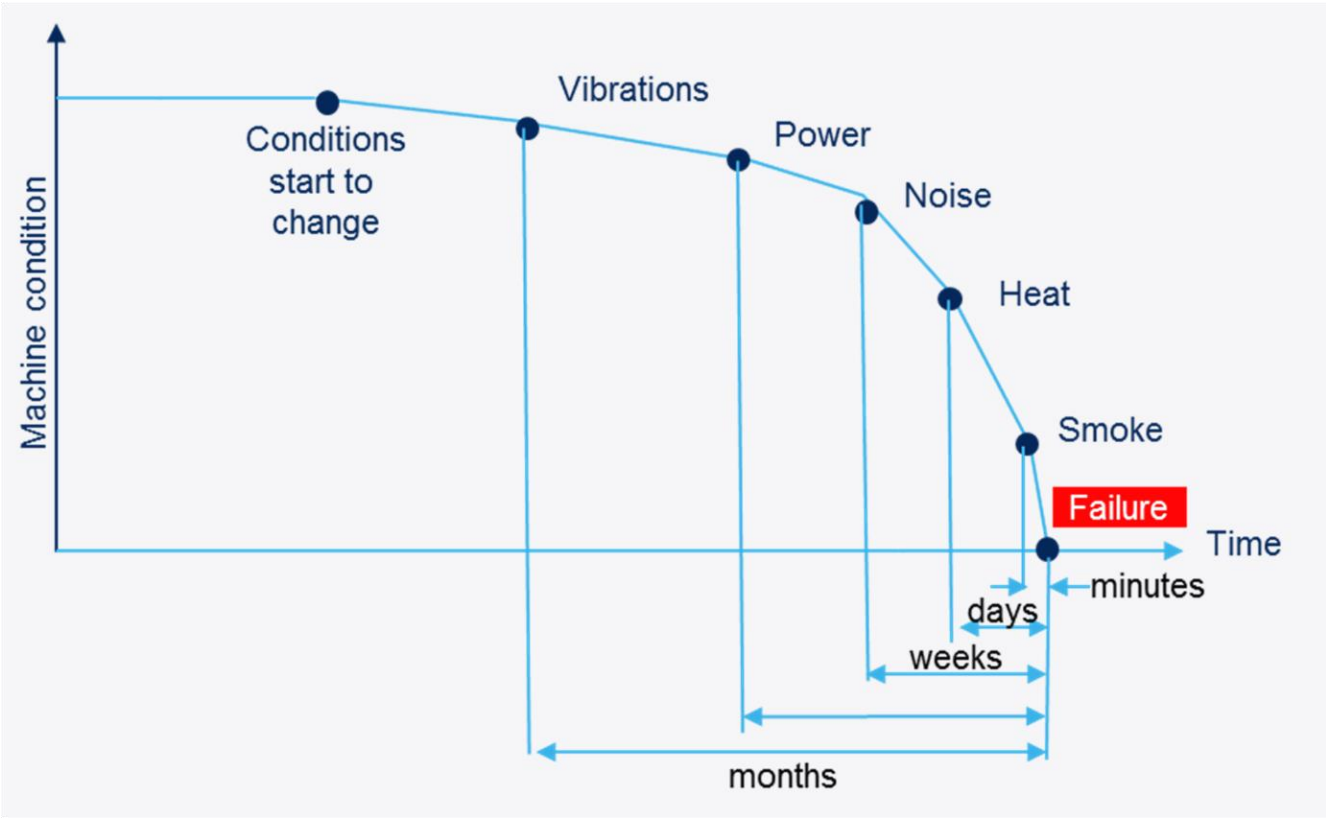
Predictive maintenance starts with condition monitoring

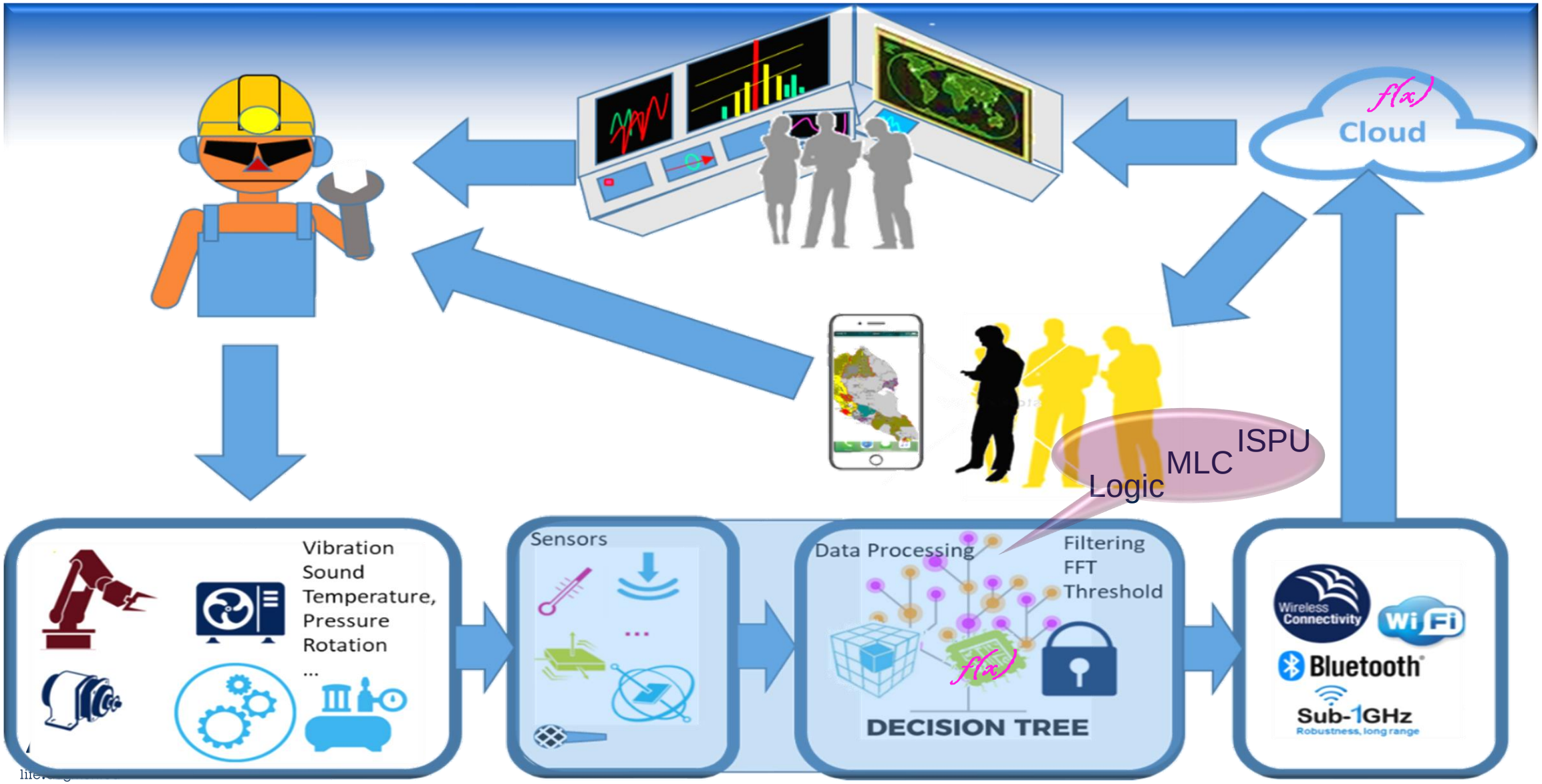
A different business model based on early sign detection, where sensors play a key role

Activities	Tradition	Predictive maintenance
Failure prevention	NA	Yes
Health condition	NA	Yes
Interactive	Human ➔machine	Machine ➔human
Diagnostic tool	Human	Sensor





Topology of industrial 4.0
The ecosystem



Predictive maintenance contributing to profits

12% Savings of scheduled repair costs

Reduction of cost due to maintenance **30%**

50% Reduction of machine downtime

Fewer breakdowns **70%**

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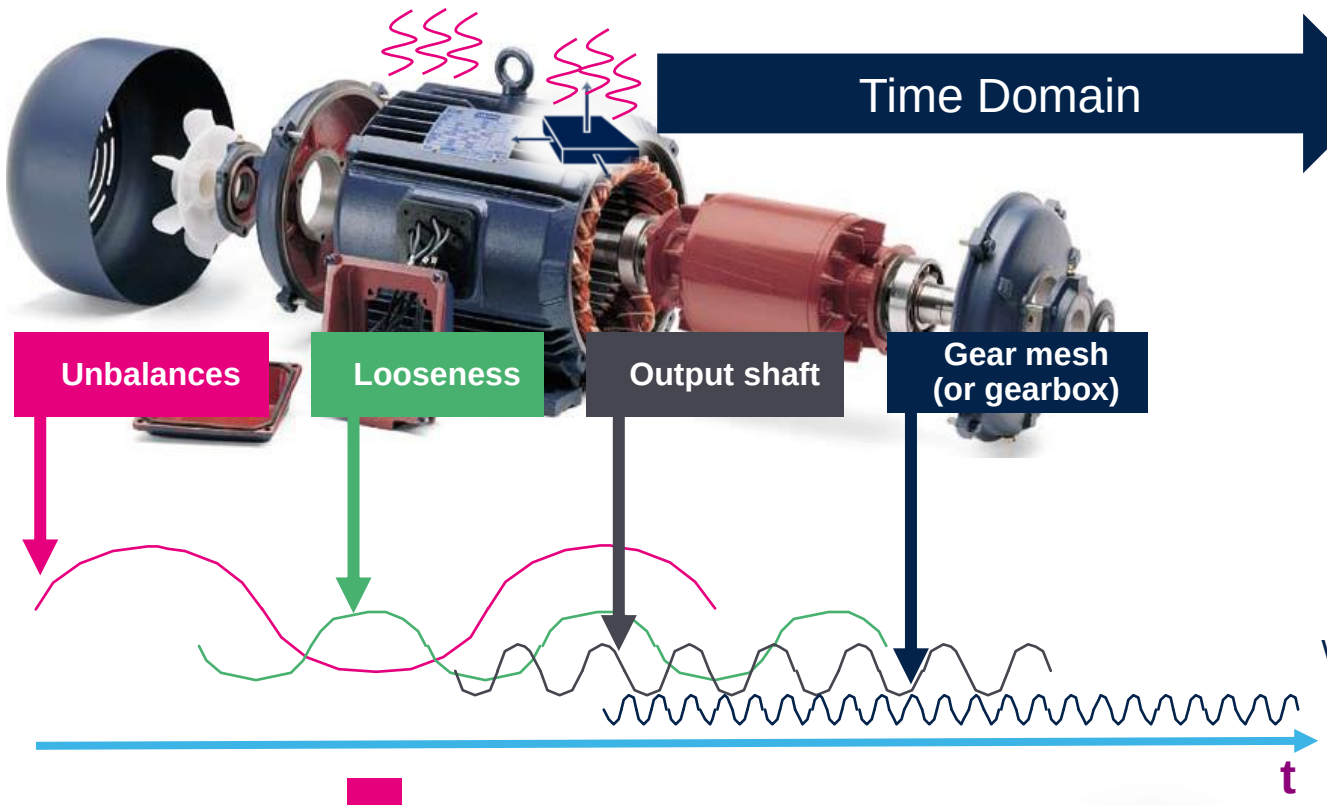
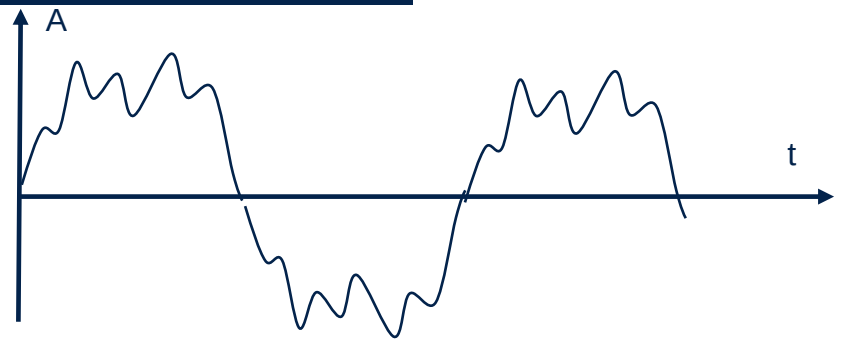
Source: Accenture analysis on predictive maintenance

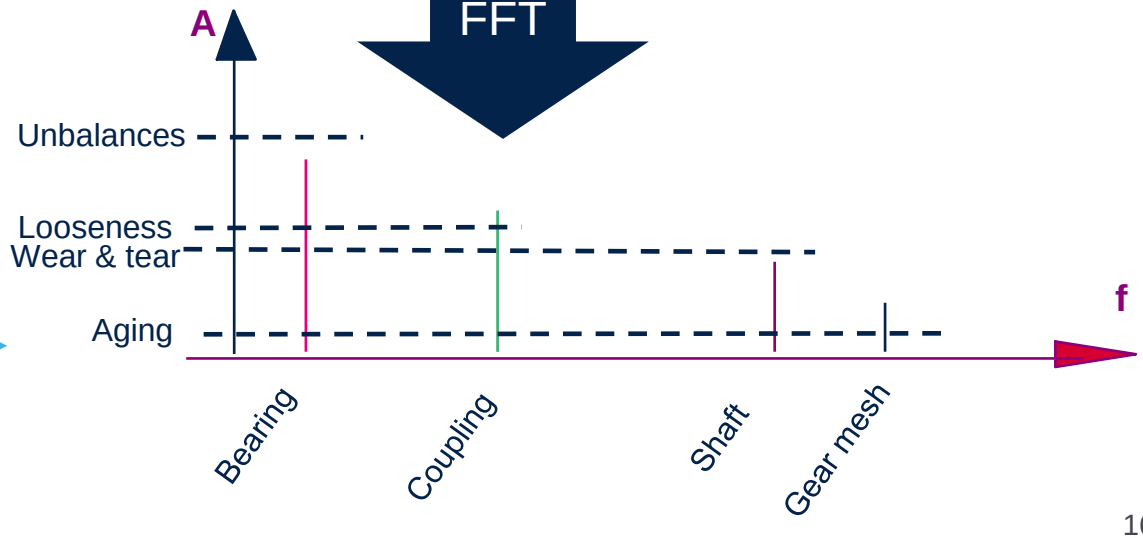
Vibration monitoring use-case with accelerometer

When we consider mechanical vibrations, a typical architecture becomes…

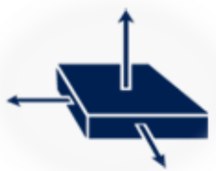




FFT



All of this is monitored by MEMS accelerometer



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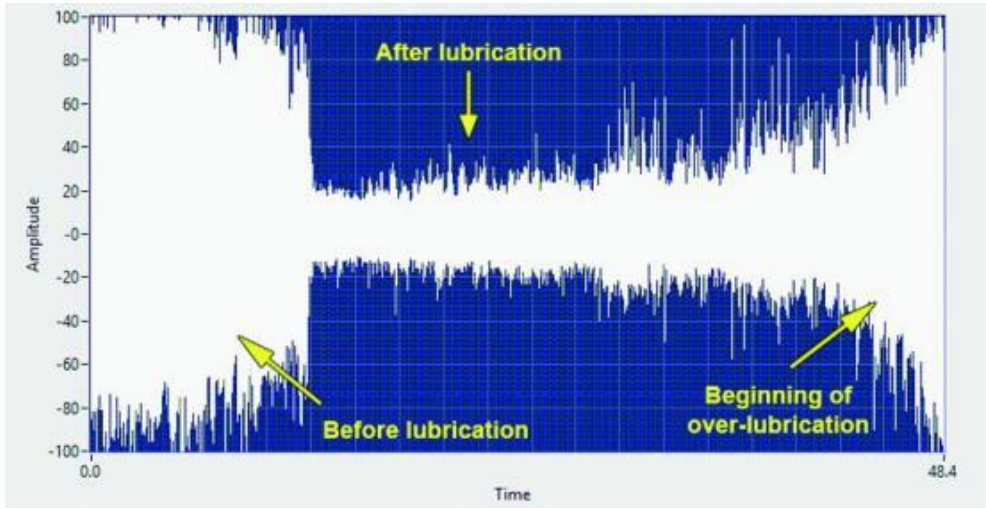
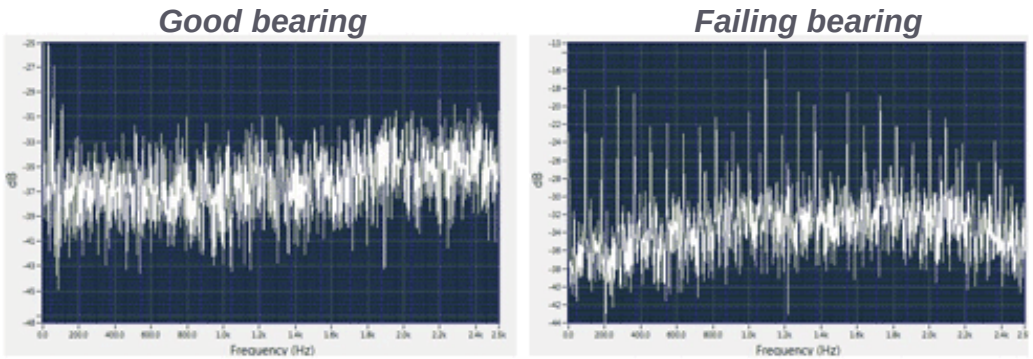
Predictive monitoring using audio

Most common maintenance applications that can be applied at your plant today:

- Air leak detection of compressed air equipment
- Vibration monitor: all rotating equipment produces frictional forces with high-frequency ultrasonic signatures that are often masked by ambient plant noise and low frequency vibrations
- Compressor valve inspections
- Acoustic lubrication
- Heat exchanger and condenser leaks
- Hydraulic systems
- Pump cavitation

Amplitude and frequencies matter





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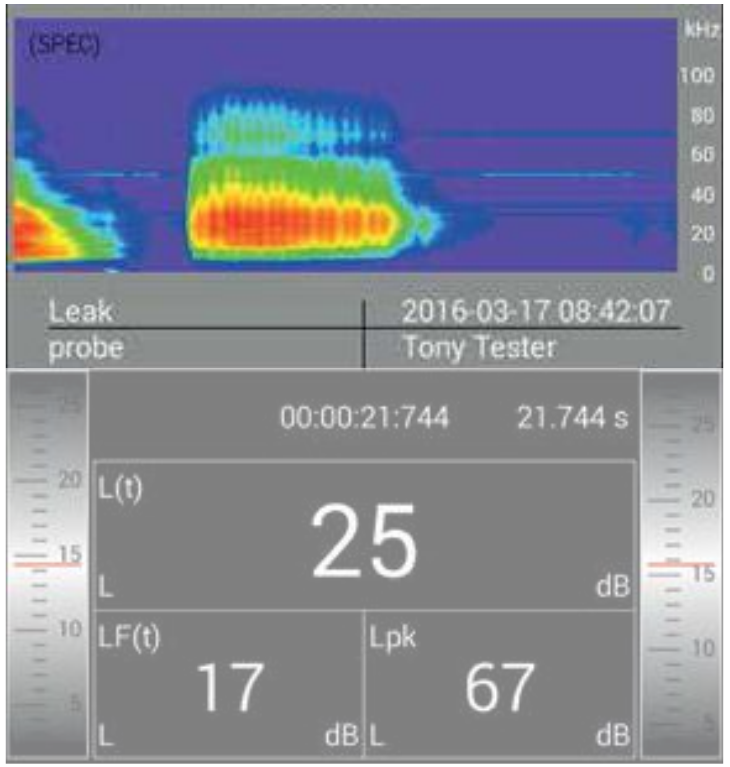
Audio frequency indicators
Ultrasound – earlier diagnostic

Post processing analysis ultrasonic frequencies to detect and classify leaks



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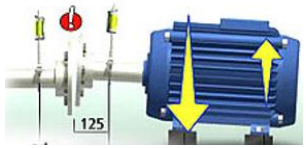
Recommended parts

Design your industrial IoT solution

Use cases






Unbalance
Looseness
Misalignment

Roller bearings
Gearing
Cavitation

Bearings
Gear Box
Lubrification

Fan bearings
Venting occlusion
Cooling failure

Type of defect/wear

Sensing technologies

Acoustic

IMP23ABSU

IMP34DT05

Inertial

IIS3DWB

ISM330DLC/DHCX(MLC)/IS(DSP)

IIS2DH/LPC

Mechanical vibration & sound analysis (10-10KHz)

Ultrasound analysis

Bandwidth needed

2Khz 3Khz 5Khz 10Khz 50Khz 80Khz

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ST sensors longevity program

6-axis IMU

I3G4250D

4 x 4 x 1 mm

- 3-axis digital gyroscope
- High linearity and stability over temperature and time

ISM330DLC

2.5 x 3 x 0.86 mm

- Dual Channel output
- Low power
- Smart features
- Axel with wide BW (3kHz) and low noise

- Cur Cons HP: **0.75 mA** combo
- FS: **gyro** up to **2000 dps; axel** up to **16 g**

ISM330DHCX

2.5 x 3 x 0.86 mm

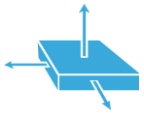
- **Enhanced machine learning core and FSM**
- **High accuracy and stability: (BI: 3°/hr)**
- **Axel with wide BW (3kHz) and low noise**

- Cur Cons HP: **0.90 mA** gyro; **1.2 mA** combo
- FS: **gyro** up to **4000 dps; axel** up to **16 g**
- Extended top: **-40°C +105°C**

MP: Q2 2019

Axel

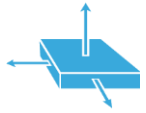
IIS2DH



2 x 2 x 1 mm

- Low power
- Wide BW (2 kHz)

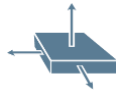
IIS2DLPC



2 x 2 x 0.7 mm

- Ultralow power
- High versatility: on the fly changes from ultralow power to high resolution/high performance modes

IIS3DWB

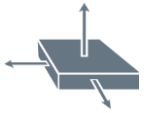


2.5 x 3 x 0.86 mm

- **3-axis digital axel**
- **Ultra wide and Flat bandwidth (>5Khz)**
- Low noise (90 µg/√Hz)
- Low power (1.1mA)
- Extended top: **-40°C +105°C**
- **Ideal for vibration monitoring**

MP: Q3 2019

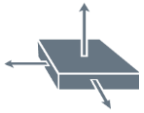
IIS328DQ



4 x 4 x 1.8 mm

- Extended top: -40°C +105°C
- QFN package

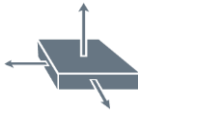
IIS3DHHC



5 x 5 x 1.7 mm

- **3 axis digital inclinometer**
- High resolution and stability over temperature and time
- High end ceramic package

IIS2ICLX



5 x 5 x 1.7 mm

- **2 axis digital inclinometer**
- **Enhanced machine learning core and FSM**
- Ultra High resolution and stability over temperature and time
- Low power
- Extended top: **-40°C +105°C**

- Cur Cons: **0.42 mA**
- FS: **± 0.5/1.0/2.0/4.0**

MP: Q3 2019

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Real edge computing with Machine Learning core

Simple, intuitive, and extremely low power

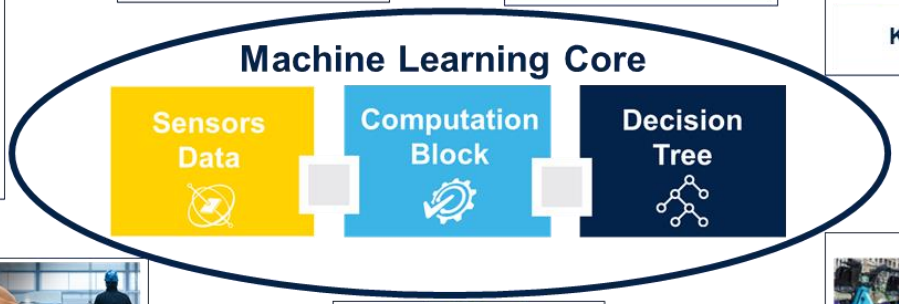
- Mean
- Variance
- Energy
- Peak-to-Peak
- 0 crossing
- Peak detector
- Min & Max

Context recognition


IoT nodes/beacons


Smart Eyewear


Kids' Tracker




Social Distancing

Man Down Detection


Sharing Bikes

Activity recognition
Gym activity recognition
Airplane mode detection

LSM6DSOX
MLC: 256 nodes
FS: ±2000 dps, ± 16 g
G_OffDr: ±0.010 dps/°C
Cus cons: 0.55 mA combo
T_{OP}: -40°C +105°C

Virtual Reality
Sensor Fusion
Vehicle stationary detection

LSM6DSRX
MLC: 512 nodes
FS: ±4000 dps, ± 16 g
G_OffDr: ±0.005 dps/°C
Cus cons: 1.2 mA combo
T_{OP}: -40°C +85°C

Smart antennas
Industrial IoT
Dynamic inclinometers

ISM330DHCX
Industrial
MLC: 512 nodes
FS: ±4000 dps, ± 16 g
G_OffDr: ±0.005 dps/°C
Cus cons: 1.2 mA combo
T_{OP}: -40°C +105°C

Structural health monitoring
Leveling instruments
Equipment installation and monitoring

IIS2ICLX
MLC: 512 nodes
FS: ± 3 g
Ultra low noise: 15µg/√Hz
X_OffDr: <0.075 mg/°C
T_{OP}: -40°C +105°C

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ISPU added value

Ultra low power consumption
- Efficiency of the embedded DSP (digital signal processing)
- Very low data exchange with external MCU (MCU stay in sleep mode most of the time)

Ultra low latency
- Processing / decision taken directly in the sensor

Easily programmable with C language or with commercial or open-source AI models

NANOEDGE AI

Data privacy & security
- Sensor data are locally processed and not provided outside

Integration / miniaturization
- MEMS mixed-signal state-of-the-art technology node
- No special purpose package

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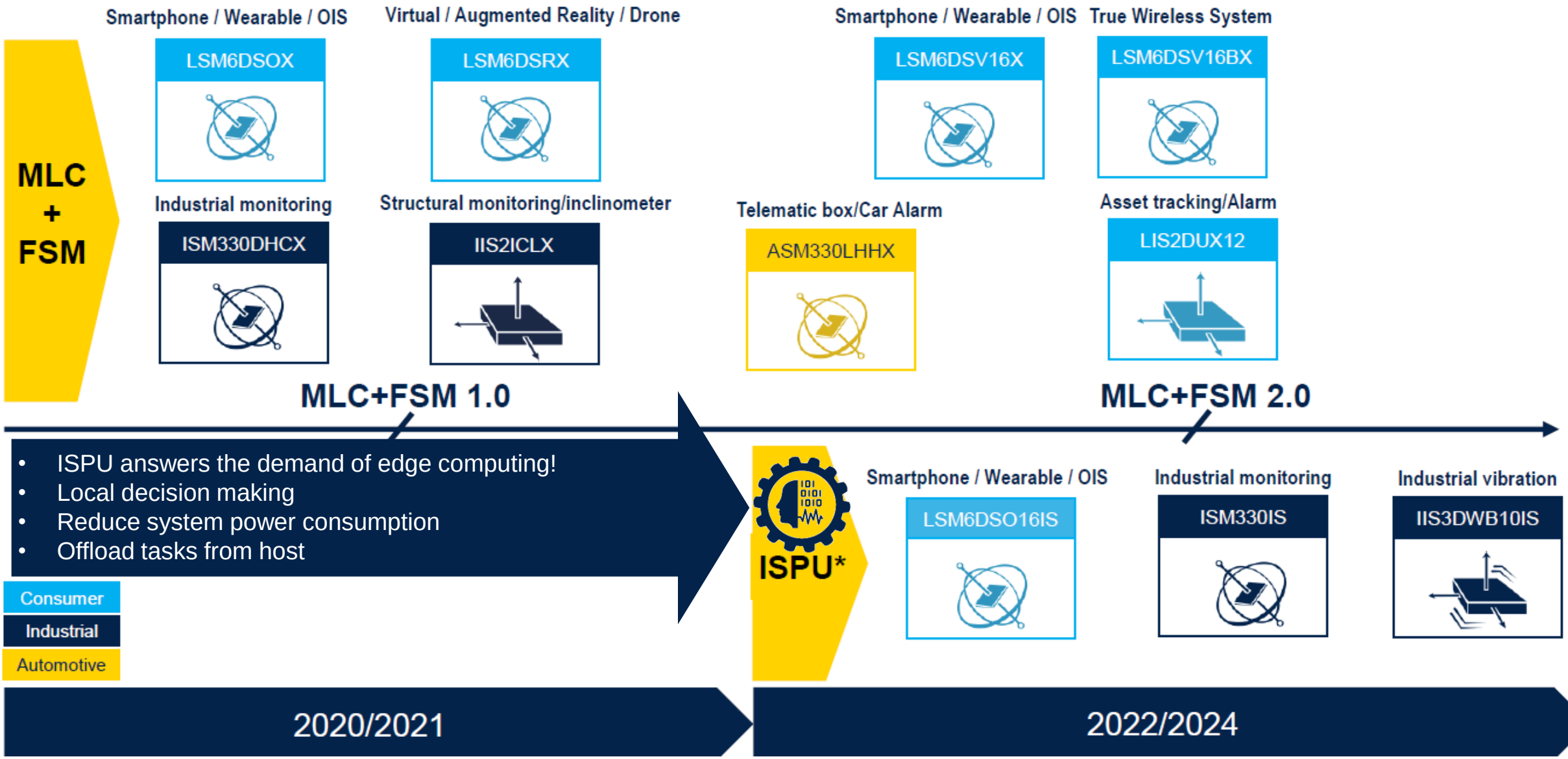
Intelligent sensor processing unit (ISPU)



Our technology starts with You

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