Precise Inclinometers for Structural Health Monitoring and Antenna-Positioning Mechanisms for Communication Systems

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Technology Tour 2019

Dallas-Richardson, TX | March 7

Agenda

→ ST Product Offerings

→ Brief Overview of Product Specifications

→ Calibration Methods & Tilt Calculation

→ Application Examples

SENSORS & Applications

CONSUMER

Available in 2019

- AXL
- 6-axis IMU
- Mag, E-compass
- Microphone
- Pressure, Humidity, Temperature

Applications

IOT
Wearable
Alarm
Smart Home
Remote Control
Voice Assistant

INDUSTRIAL

LONGEVITY 10 YEARS COMMITMENT

- AXL
- 6-axis IMU
- Mag, E-compass
- Microphone
- Dedicated AXL

Indus Robot
Positioning
Tracking
Tilt
Vibration

AUTOMOTIVE

AEC-Q100 COMPLIANT
PPAP LEVEL-3 AVAILABLE

- AXL
- Gyro
- 6-axis IMU

Alarm
E-call
Telematic
Vehicle tracking

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SENSORS

ST offer

CONSUMER


AXL


6-axis IMU


Mag, E-compass


Microphone


Pressure, Humidity, Temperature

LPS22HH
LPS33W
LPS27HHW
LSM6DSO
LSM6DSR
LSM6DSRX
LIS2DTW12
LSM6DSOX
HTS2
STTS22H
MP23DB01HP
MP34DT06J
MP23DB02MM

IOT
Wearable
Alarm
Smart Home
Remote Control
Voice Assistant

INDUSTRIAL


AXL


6-axis IMU


Mag, E-compass


Microphone


Dedicated AXL

IIS2DLPC
IIS2ICLH
IIS3DHHC
ISM330DHC
IIS3DWB
ISM330DLC
IMP34DT05

Indus Robot
Positioning
Tracking
Tilt
Vibration

AUTOMOTIVE


AXL


Gyro


6-axis IMU

AIS2IH
ASM330LHH
AIS2DW12

MP in 18H2
MP in 19H1

Alarm
E-call
Telematic
Vehicle tracking

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SENSORS & MOTION MEMS

ST offer

INDUSTRIAL

Available in 2018	Available in 2018	New products for H1 2019
AXL	IIS2DLPC	IIS2ICLH
6-axis IMU	IIS3DHHC	IIS3DWB
Mag, E-compass	ISM330DHC	
Microphone	IMP34DT05	
Dedicated AXL		

Indus Robot
Positioning
Tracking
Tilt
Vibration

- IIS2DLPC, IIS3DHHC, IMP34DT05-A: in Mass Production
- ISM330DHC: Mass Production targeted in 19Q1
- IIS2IDCLH, IIS3DWB: Mass Production targeted begin of 19Q2

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Brief Overview of Product Specifications

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IIS2DH, IIS2DLPC, IIS3DHHC

INDUSTRIAL Accelerometer / Inclinometer

IIS2DH

- ±2 to ±16g FS Accelerometer
- **Up to 12 bit resolution** for Performance and Embedded Functionalities. **LPM** & **HRM** available
- Power consumption:
  - **6µA/11µA** in **LPM/HRM** (@50Hz)
  - **2µA** in **HRM** (@1Hz)
- Embedded features (Interrupts, Filters, FIFO, Temperature sensor, Self-Test)

IIS2DLPC

- ±2 to ±16g FS Accelerometer
- From **12 to 14 bit** resolution, Low Power and High Performance Modes, low noise enabled fct
- Ultra Low Power:
  - **0.38µA** in Low Power Mode @1.6Hz
  - **3µA** in Low Power Mode @50Hz
  - 90 / 120µA in HPM @1.6kHz
  - **50nA** in PD
- single shot and ODR from **1.6 to 1.6kHz**, FIFO, Temperature sensor, Self-Test, Interrupts

IIS3DHHC

- 3-axis Inclinometer
- ±2.5g Full Scale, **45µg/√Hz** noise
- BW 235, 440Hz
- Temperature behavior optimized:
  - **< 0.4 mg/K**
  - **0.7%** sensitivity change
  - Ceramic package
- Embedded features (Filters, FIFO, Temperature sensor, Self-Test)
- **Enable to reach ~1.5° accuracy over temp & time**

Common Features

Industrial applications
10Years longevity

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IIS2ICLH, IIS3DWB

INDUSTRIAL Inclinometer / Vibrometer

NEW

*Coming soon! Q2 2019

IIS2ICLH*

- 2-axis accelerometer for high performance inclinometer
- Full scale from **±0.5** to **±4g**
- BW from 25 to 200Hz
- **20µg/√Hz noise**
- High Temperature performance:
  - **0.05 mg/K**
  - -40 to 105°C temperature range
- **Enable to reach <0.5° accuracy over temp & time**

IIS3DWB*

- 3-axis accelerometer for vibration monitoring
- From ±2 to 16g Full Scale, 90µg/√Hz noise
- BW **5kHz** (ODR @26.6kHz)
- -40 to **105°C** temperature range
- Embedded features (Filters, FIFO, Temperature sensor, Self-Test)

10 Years longevity
Industrial sensors

Dedicated Accelerometers

Industrial applications
10Years longevity

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IIS3DHHC - Digital Inclinometer

High Resolution, High Stability

Features

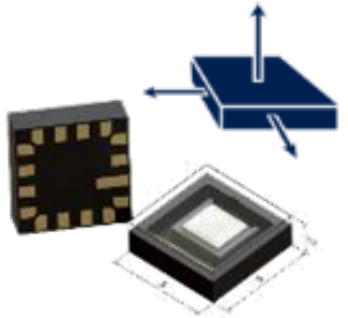
- 10 years longevity commitment
- 3-axis, ±2.5 g Full Scale
- Ultra Low noise: 45 µg/√Hz
- High-stability (offset and sensitivity) over temperature and time
- Digital features (FIFO & Interrupts) to reduce power consumption at system level
- High end Ceramic Package: LGA 16-lead, 5x5x1.7mm3

Applications

- Precision Inclinometer
- Antenna and platform pointing and leveling
- Structural health monitoring
- Leveling Instruments

Benefits

- Continuity and stability of the component supply
- Ultra high resolution
- High stability over temperature and over time
- High end ceramic package
- Ideal solution for accurate inclination sensing



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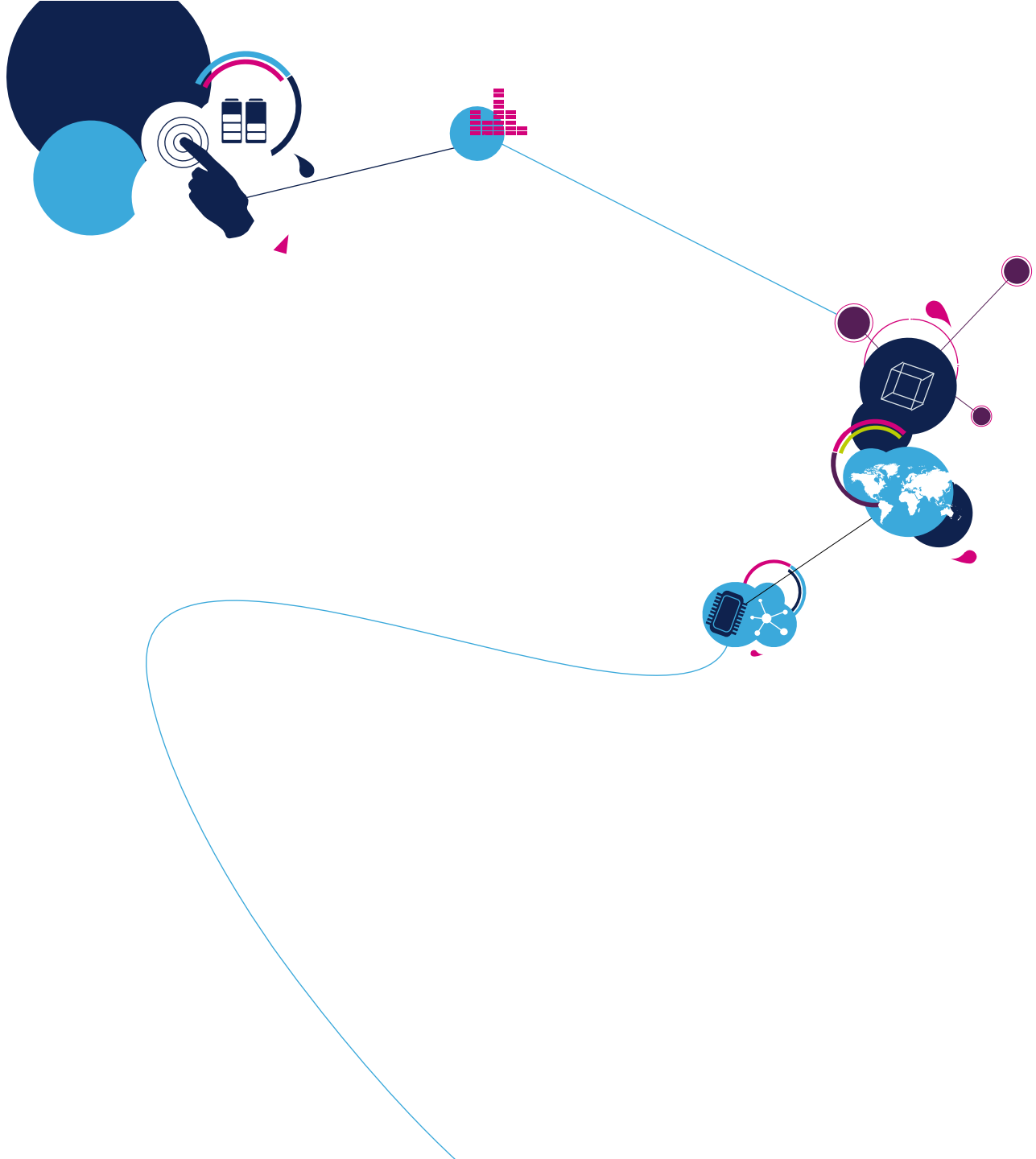

Calibration Methods & Tilt Calculation

Using an Accelerometer

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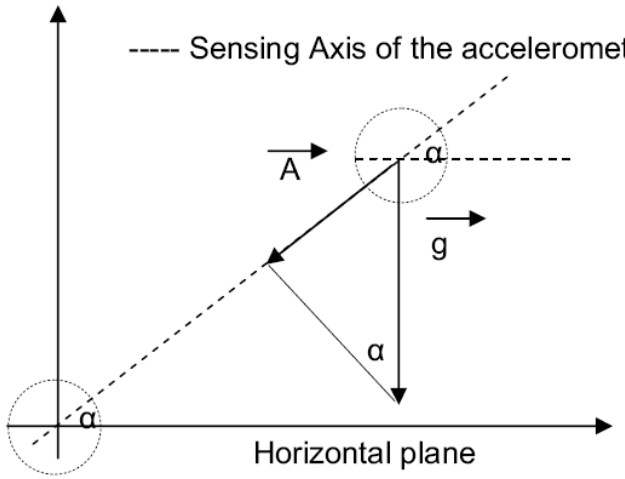
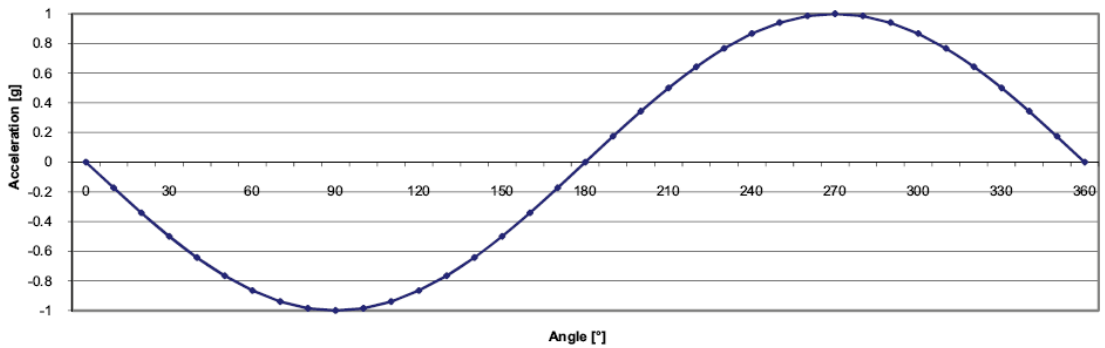
Tilt Calculation Using an Accelerometer

The Basic Concept

- The accelerometer measures the projection of the gravity vector on the sensing axis.
- The amplitude of the sensed acceleration changes as the sine of the angle α between the sensitive axis and the horizontal plane



Single axis sensing along 360° rotation



$$\alpha = \arcsin\left(\frac{a}{g}\right)$$

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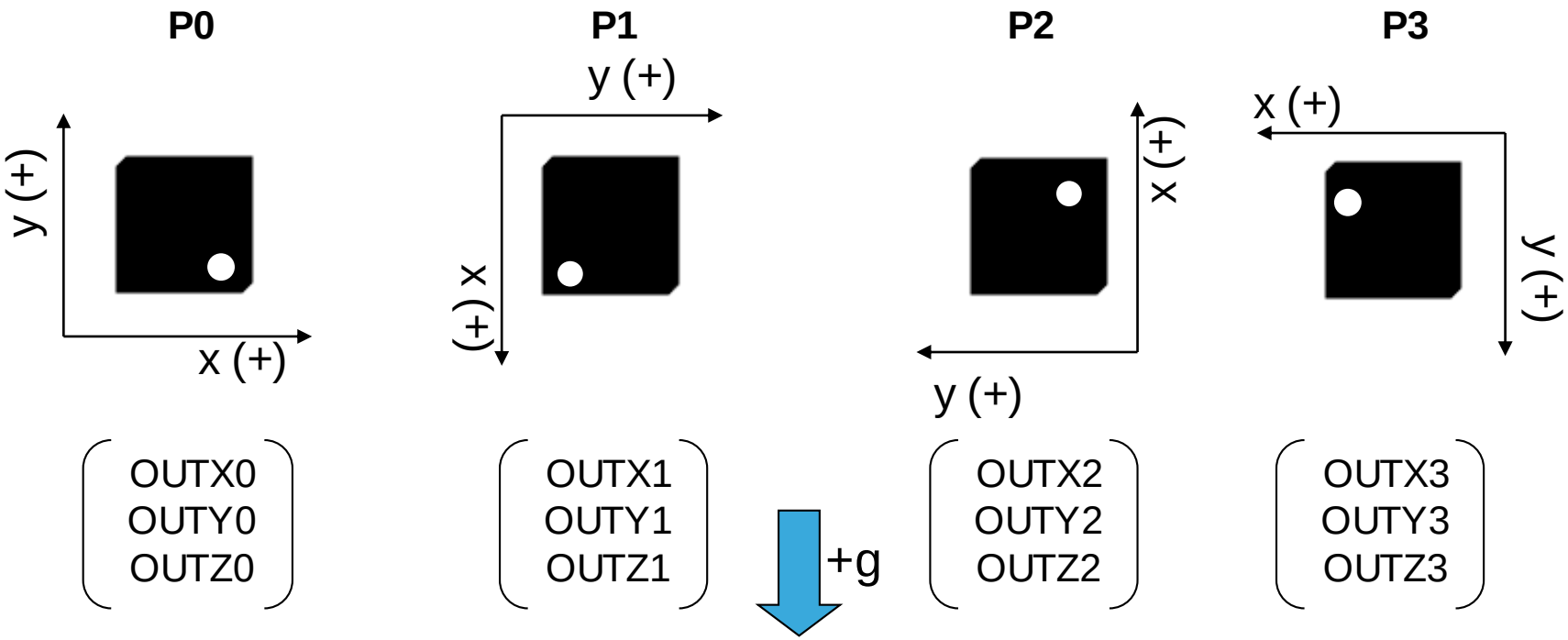
Parameters Calibration For Tilt Calculation

- In order to get accurate tilt calculation using MEMS accelerometers, the following parameters need to be calibrated:
  - Zero-g level offset and sensitivity accuracy
  - Non linearity
  - Cross axis sensitivity
  - Offset and sensitivity drift over temperature

Positions Required for Calibration



- Consider the 4 positions of above and the sensor outputs recorded on each position for a 2-axis accelerometer.

Calibration Formulas (1/2)

- Each sensor axis can be calibrated using the following parameters:
  - Offset (OFFX, OFFY) [LSB]
  - Sensitivity (SENSX, SENSY) [LSB/g]
  - CrossAxis (CXY, CYX) []

- Such parameters can be estimated using the 4 positions in the previous slide using the following approach:

  OUTX = OFFX + SENSX * (ACCX + ACCY * CXY)/1000 [LSB]

  OUTY = OFFY + SENSY * (ACCX * CYX + ACCY)/1000 [LSB]

  where ACCX and ACCY are the real acceleration along X and Y (expressed in ‘g’)

Calibration Formulas (2/2)

- The parameters will be estimated as follow:

  OFFX = (OUTX0 + OUTX1 + OUTX2 + OUTX3)/4

  SENSX = (OUTX2 – OUTX1)/2

  CXY = (OUTX0 – OUTX3)/(2 * SENSX)

  OFFY = (OUTY0 + OUTY1 + OUTY2 + OUTY3)/4

  SENSY = (OUTY0 – OUTY3)/2

  CYX = (OUTY2 – OUTY1)/(2 * SENSY)

  Where OUTXK is the Output in the K position (See slide 1)

- Then solve iteratively to obtain estimated real acceleration value (ACCX', ACCY'):

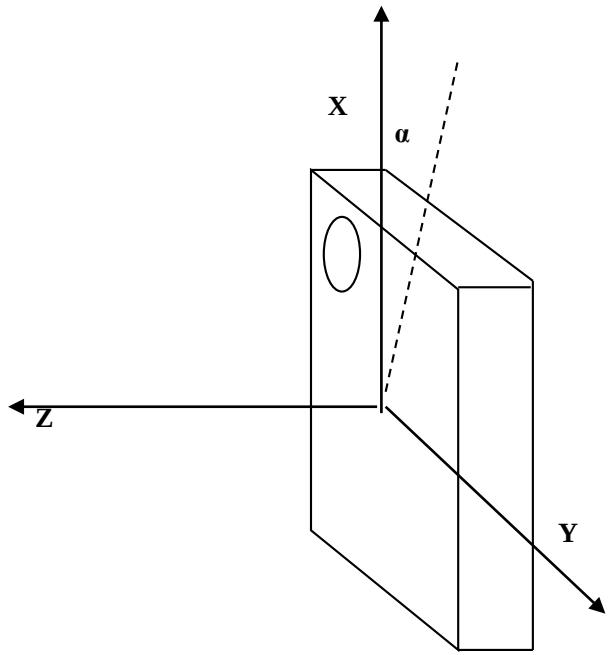
  ACCX' = (OUTX – OFFX) / SENSX – ACCY' * CXY

  ACCY' = (OUTY – OFFY) / SENSY – ACCX' * CYX

From Calibrated Data to Tilt Angle

- Once the calibration parameters have been applied to the raw data from the accelerometer, the tilt angle can be calculated with the following formula:

$$\alpha = \arctan\left(\frac{ACCX'}{\sqrt{(ACCY')^2}}\right)$$

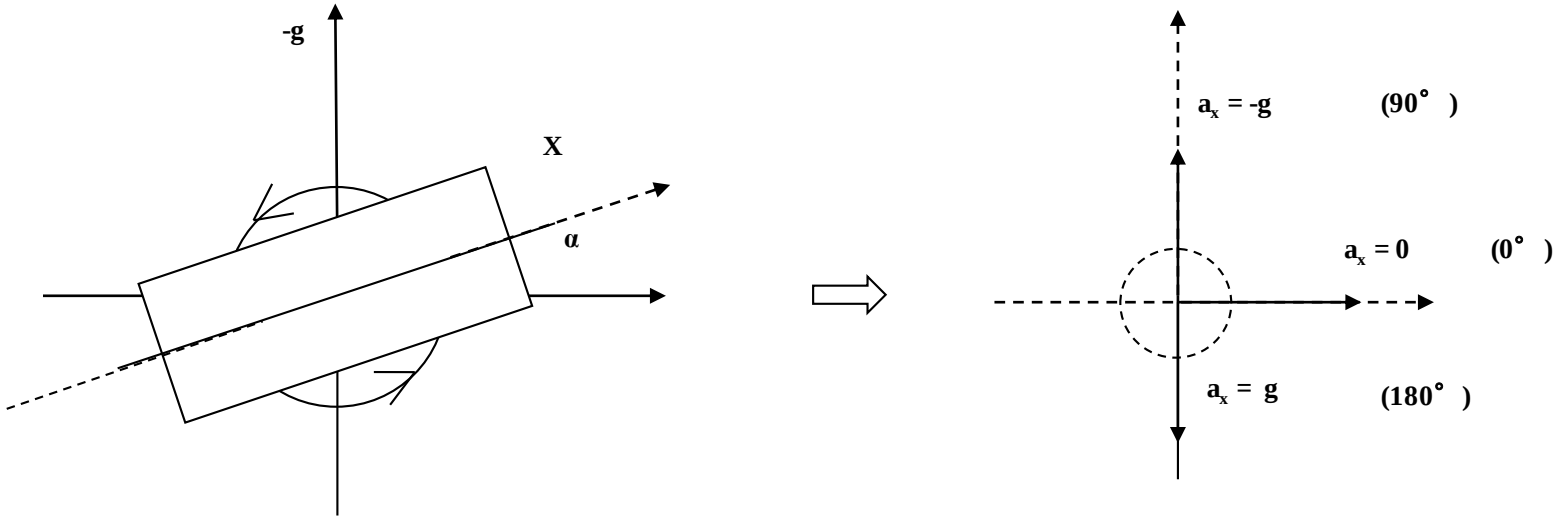


Where ACCX' and ACCY' represent acceleration data after applying calibration formulas.

Sensitivity Variation With Angle

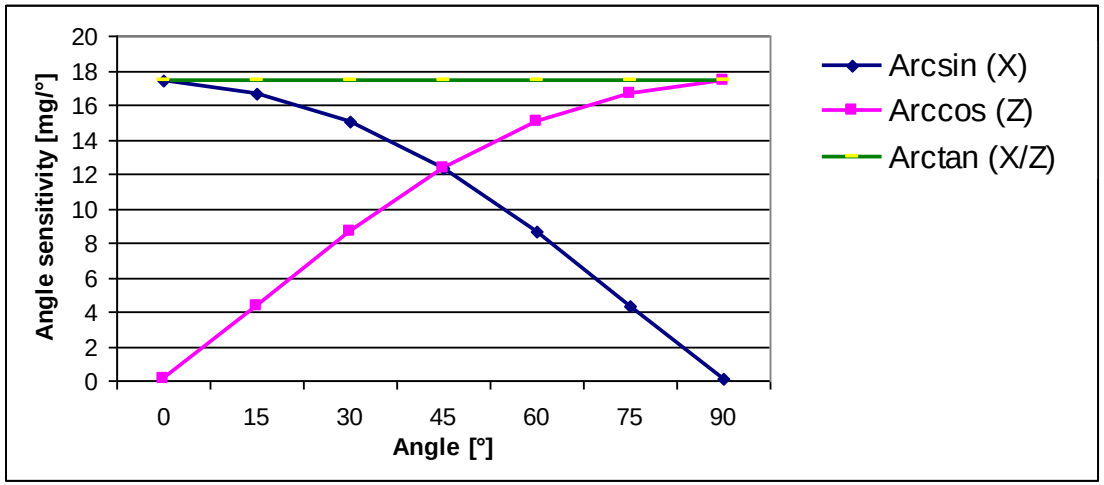
- When the sensing axis is perpendicular to the force of gravity the sensitivity is approximately:
  17.45mg/° = [sin (1°) – sin (0°)]

- Due to the derivate of the *sin* function the sensor is less sensitive to tilt angle changes when the sensing axis is close to ±1g.
  0.15mg/° = [sin (90°) – sin (89°)]



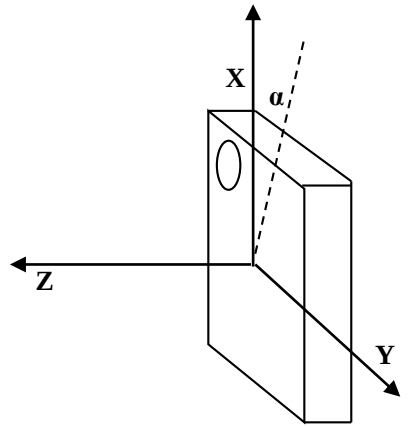
Constant Sensitivity

- Thanks to this approach, sensitivity can be kept constant along a 360° rotation



- The same concept applies to 2-axis tilting on the vertical plane considering $a_z = 0$.

$$\alpha = \arctan\left(\frac{a_X}{\sqrt{(a_Y)^2 + (a_Z)^2}}\right) \longrightarrow \alpha = \arctan\left(\frac{a_X}{\sqrt{(a_Y)^2}}\right)$$



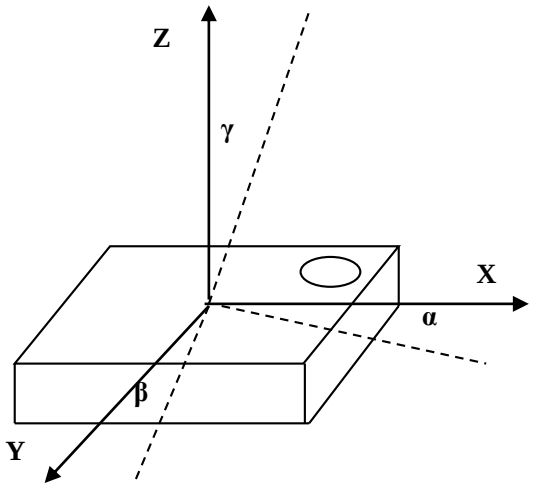
3-axis Tilt Calculation

- To measure the tilting independently from 3D space orientation, it's required to use 3-axis linear accelerometer that is able to sense the vector of gravity along all the 3 axes X,Y & Z.

- Trigonometric equations allow to express the angle α & β as a function of a_X, a_Y, a_Z as follow:

$$\alpha = \arctan\left(\frac{a_X}{\sqrt{(a_Y)^2 + (a_Z)^2}}\right)$$

$$\beta = \arctan\left(\frac{a_Y}{\sqrt{(a_X)^2 + (a_Z)^2}}\right)$$



Inclinometer

Application Block Diagram

HW

Wireless (Option)

DCDC (ST1PS01)
LDO (STLQ020)

SubGHz (S2-LP)
BLE (BlueNRG)

Wired

OpAmp (TSZ182)
Current measurement

MCU (STM32)

MEMS IIS3DHHC

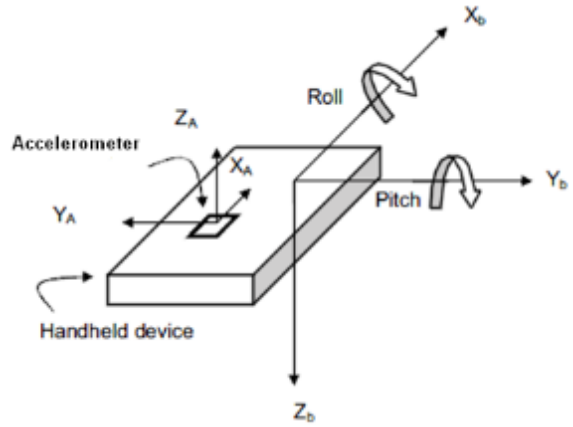
DCDC (L7987, …)
LDO (ST732, …)
Battery → 3.3V

SW

- MotionTL (Tilt) → Angle
- Accelerometer calibration (offset, gain)

$$\text{pitch} = arctan\left(\frac{A_x}{\sqrt{{A_y}^2 + {A_z}^2}}\right)$$

$$\text{roll} = arctan\left(\frac{A_y}{\sqrt{{A_x}^2 + {A_z}^2}}\right)$$



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Inclinometer:

Accuracy Estimations

Key Parameters (KPIs)	Note	Typical Error - illustrative data	
		[mg]	[°]
Zero-g offset	No calibration	30	1.72
	With calibration	0	0
Noise	90 µg/√Hz, BW = 100 Hz	1.1	0.06
Bias drift	Short term	< 1	< 0.06
Zero-g level change vs. temperature	25°C ± 5°C	± 2	± 0.11
Total Error	*No calibration*	*34.1*	*1.95*
	With calibration	*4.1*	*0.23*

Tilt Sensors	Total error with calibration (-40 ~ 85°C)	
IIS3DHHC	26 mg	1.49 °
IIS2ICLH*	4 mg	0.23 °

*Available H1 2019

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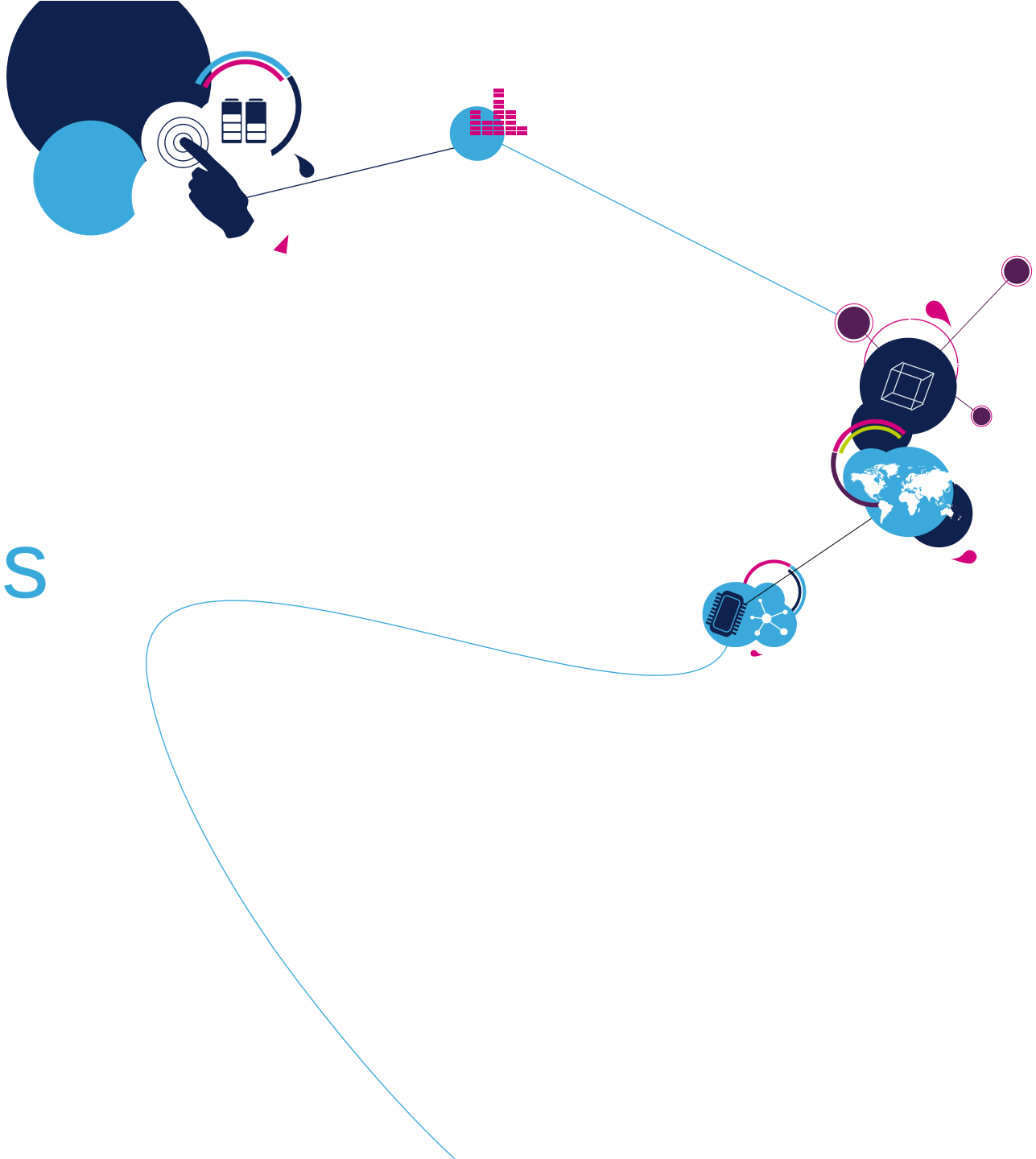

Application Examples

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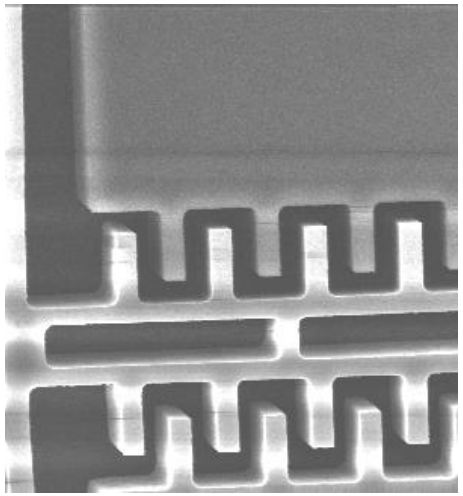
Measurements with an Accelerometer

➢Accelerometer is a system based on **silicon mechanical structure** able to sense **motion**



Acceleration
(dynamic measurement)
Physical activity monitoring

Vibration
(dynamic measurement)
Involuntary hand motion (Parkinson's diseases,..)

Inclination
(static measurement)
Adjusting stimuli levels in pacemakers

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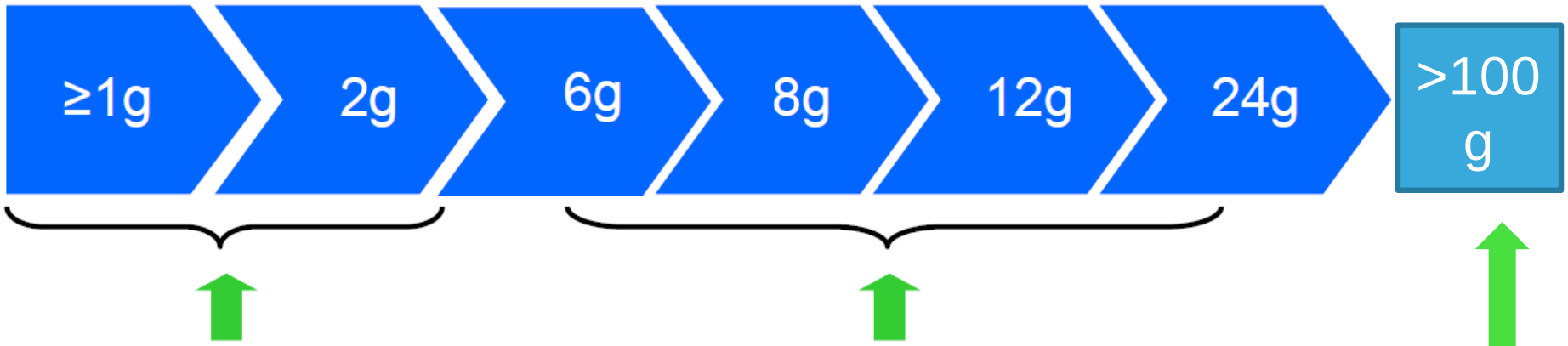
Ful-Scale Range vs. Application



Seismology, Free-fall, Vehicle Acceleration

Earth gravity, Inclination, Movement recognition, User interface

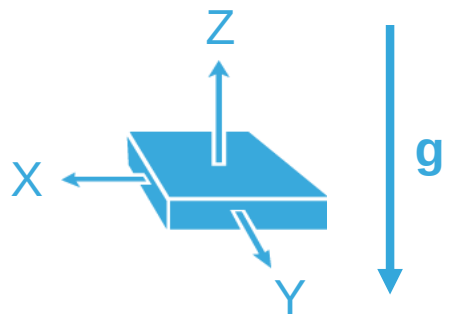
Shocks

Vibrations

Concussion
Crash

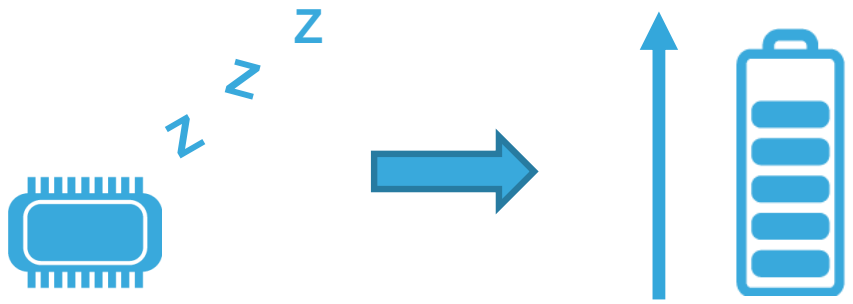
What are the key roles of an Accelerometer in Applications?

- Acceleration on the 3-axis measurement - mg

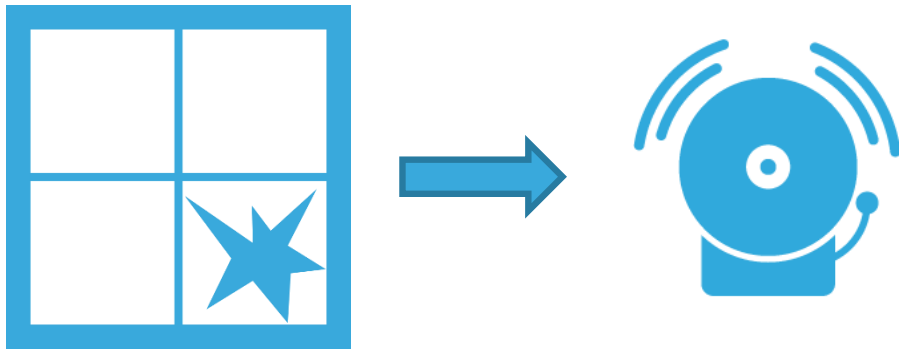


- Measure tilt, vibrations and fast acceleration variation (free-fall) in industrial applications for predictive maintenance

- Save power (cost) by using accelerometer for wakeup and standby mode



- For alarms, generate interruption to detect unexpected situation



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Accelerometer Applications

Consumer, Industrial, Automotive

Asset Tracking
Shock / WakeUp

Alarms
Tilt / WakeUp

Sport
Activity tracking / Pedometer

People monitoring
Freefall / Activity

Predictive maintenance
& Monitoring
Vibration / Tilt

White Goods
Vibration / Tilt

Industrial /Automotive Inclinometer
Positioning / Tilt

Car Alarms / PKE*
Tilt / Movement

*Passive Key Entry

And many others….

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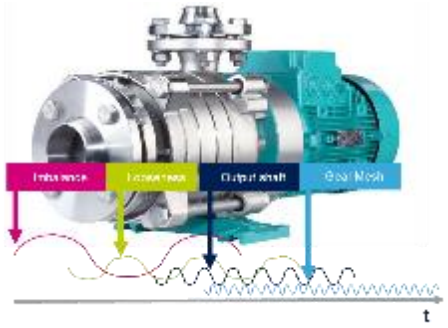
Real Time Condition Monitoring

Applications

Condition Monitoring



Smart installation

Antenna pointing

Platform Levelling

Structural Health Monitoring

Sensors

Ultra wide bandwidth, low noise, digital accelerometer for vibration monitoring

- From ±2g up to ±16g Full Scale
- 5KHz Bandwidth
- Ultra low noise (90 µg/√Hz)
- Package LGA 2.5x3x0.83

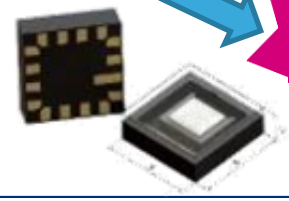
Vibrometer
IIS3DWB

MP: Q2'19

Ultra accurate, ultra high resolution digital inclinometer

- High resolution, High accuracy (<0.5° over Temp. and Time)
- Operating range -40÷105C
- High end ceramic Package 5x5x1.7 CLGA 16Lead

Inclinometers:
IIS3DHHC
IIS2ICLH



MP: Q2'19

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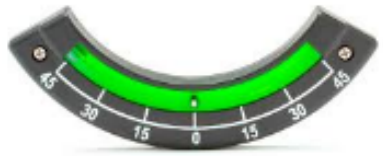
Inclinometer

Use Cases

- Scales Tilt Correction
- Compass Tilt Correction
- (Liquid) Level Sensing Tilt Correction
- Construction Equipment and Man Lift Safe Operating Angle
- Crane Boom Angle
- Platform Leveling
- Headlight Leveling

- Factory Automation
  - Precision Inclinometer
  - Robotics
- Building Automation
  - Antenna pointing and platform leveling
- Structural health monitoring
  - Position change detection

- Agricultural Systems & Vehicles
  - Leveling Instruments
  - Fork lifts, Cranes
- Hand Tools
  - Leveling Instruments (laser)



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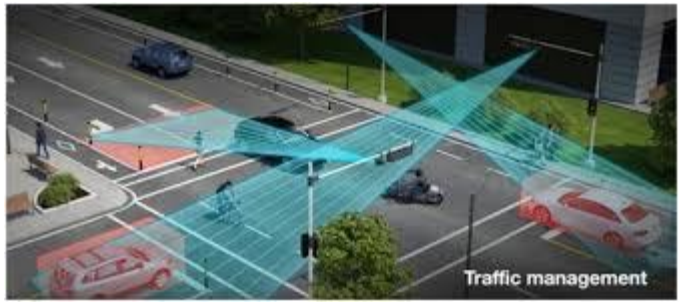
Inclinometer for Precise Positioning

Automotive applications

LiDAR position monitoring

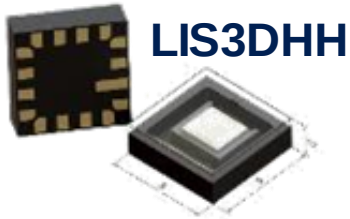


Levelling

Automatic parking brake

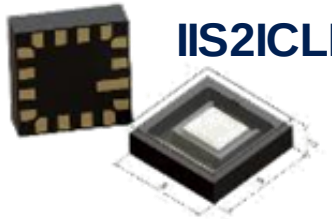
3-axes INCLINOMETER

- **High Resolution, High Stability 3-axes Digital Inclinometer**
- High-stability (offset and sensitivity) over temperature and time
- ±2.5 g Full Scale
- High End Ceramic Package 5x5x1.7 CLGA 16Lead



LIS3DHHC

- **Ultra Accurate, Ultra low Power 2-Axes Digital Inclinometer**
- High resolution, High Accuracy (<0.5° over Temp. and Time)
- Ultra Low Power (0.17mA)
- High End Ceramic Package 5x5x1.7 CLGA 16Lead



IIS2ICLH

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Thank You!

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