https://www.designengineeringexpo.co.uk/workshop-agenda-2022

MASTERCLASS IN DIGITAL SENSORS

Thursday 9th June, 2022 @ 11:00 NEC Birmingham, GB
Gopi Patel – Field Applications Engineer
EMC | Power | IoT

WÜRTH ELEKTRONIK MORE THAN YOU EXPECT

Masterclass in Digital Sensor

Agenda:

- Brief history and evolution of sensors
- Construction of mems sensor
  - Temperature, Humidity, Pressure, Accelerometer
- Electronic interface
  - I2C, SPI
  - Firmware
- Design recommendations
  - Schematic, PCB layout, EMI filtering
- Take home
  - Eval board, CAD library, SDK, software examples
  - Surprise, Q&A and Thank you

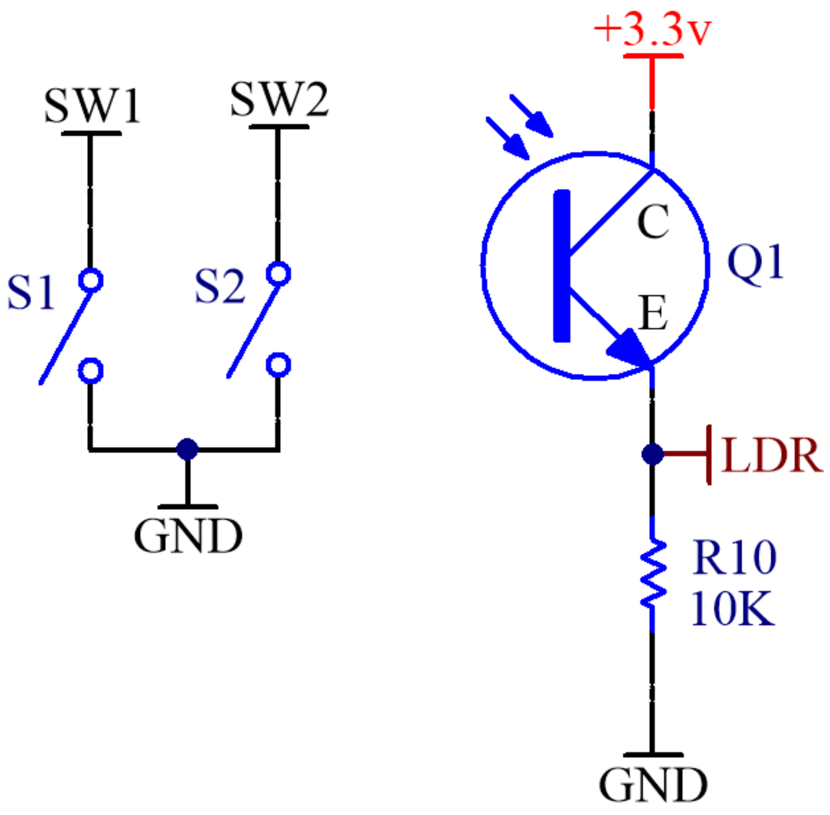
HISTORY AND EVOLUTION OF SENSORS

History and evolution of sensors

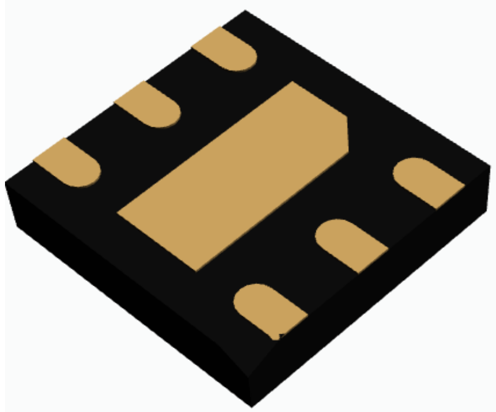
Sensors that were borne more than a century ago:
Mercury, bimetal strip, strain-gauge, spring coils etc.

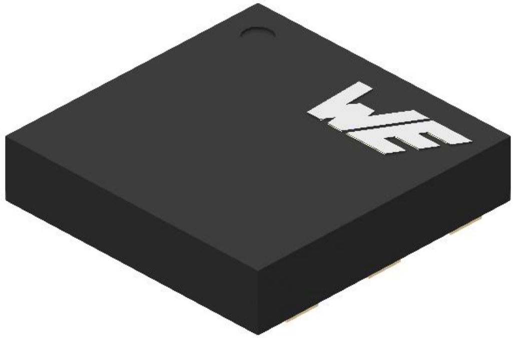
Sensors that dominates todays market:
Voltage, current, pulse, click, swipe, pressure, touch, light, temperature, occupancy, movement, angle, tilt, acceleration, rotation, free-fall, location, altitude, flow, gas, liquid, distance, motion, IR, PIR, radar, Lidar, Sonar, acoustic, microwave ...
These are capacitive, resistive, semiconductor or MEMS

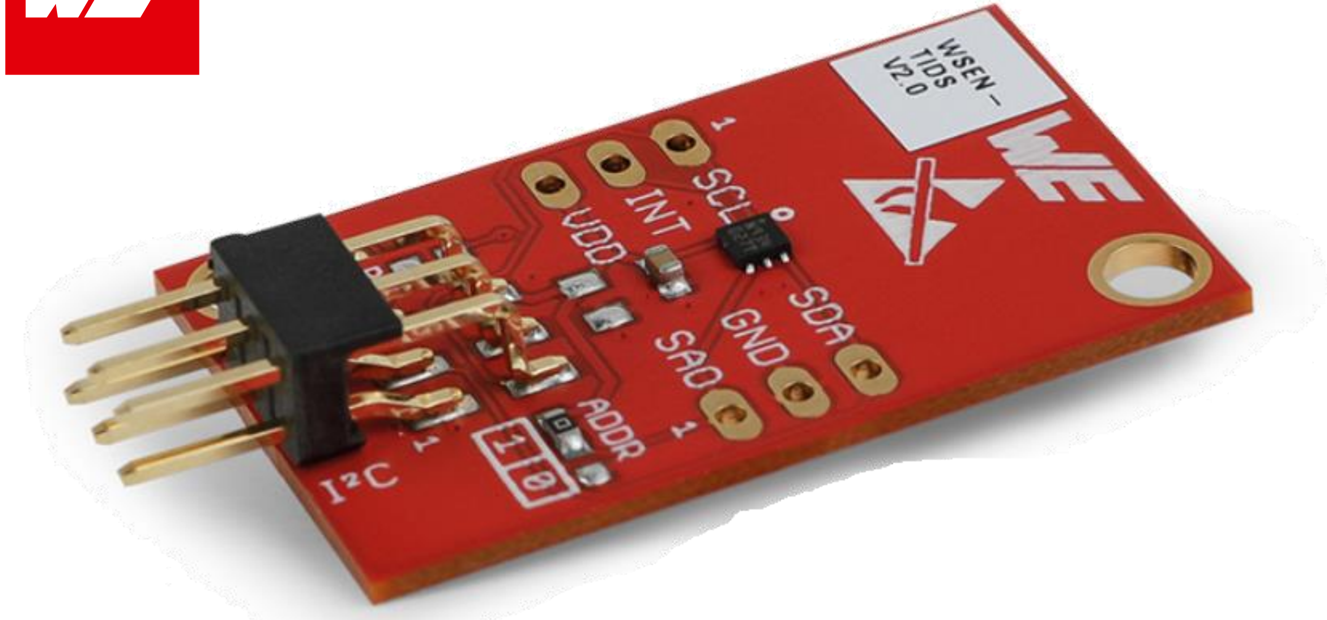
Futuristic sensors:
ToF, AoA, AoD, VOC, CO_2, CO, NO_2, SO_2, AI, VR, AR, Machine learning...



TEMPERATURE SENSOR







https://www.we-online.com/catalog/en/WSEN-EVAL_TIDS

Types of Temperature Sensors

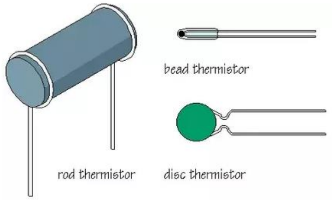
Temperature °C

-250 | -100 | -55 | 0 | 85 | 130 | 600 | 2600

Si Diode based

Silicon band-gap

FW voltage of diode



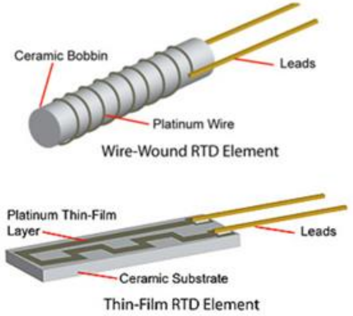
Self heating

Non-linear (NTC)

NTC/PTC

Semiconductor based…

Sulphites, silicates, Co, Ni…



https://electronics.stackexchange.com/questions/342124/how-do-resistance-temperature-detectors-rtd-work

Very high accuracy

Linear, Expensive

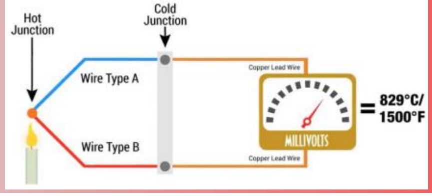
RTD

Pt, Ni, Cu based…

Non-linear, Not-stable

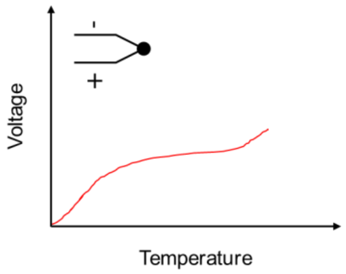
Limited accuracy

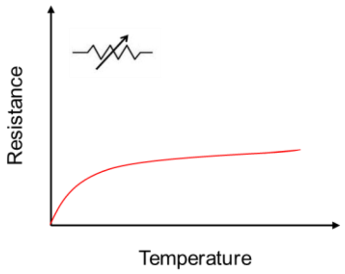
Thermocouple

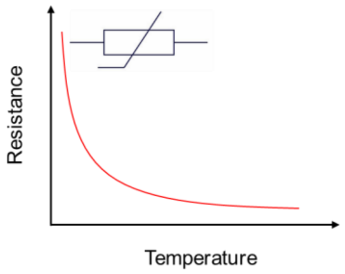


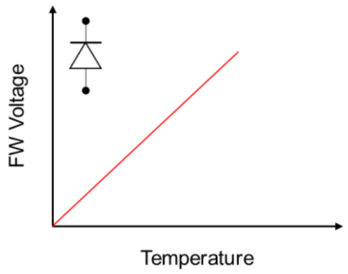
Seebeck effect

Temperature Sensor Comparison Table:



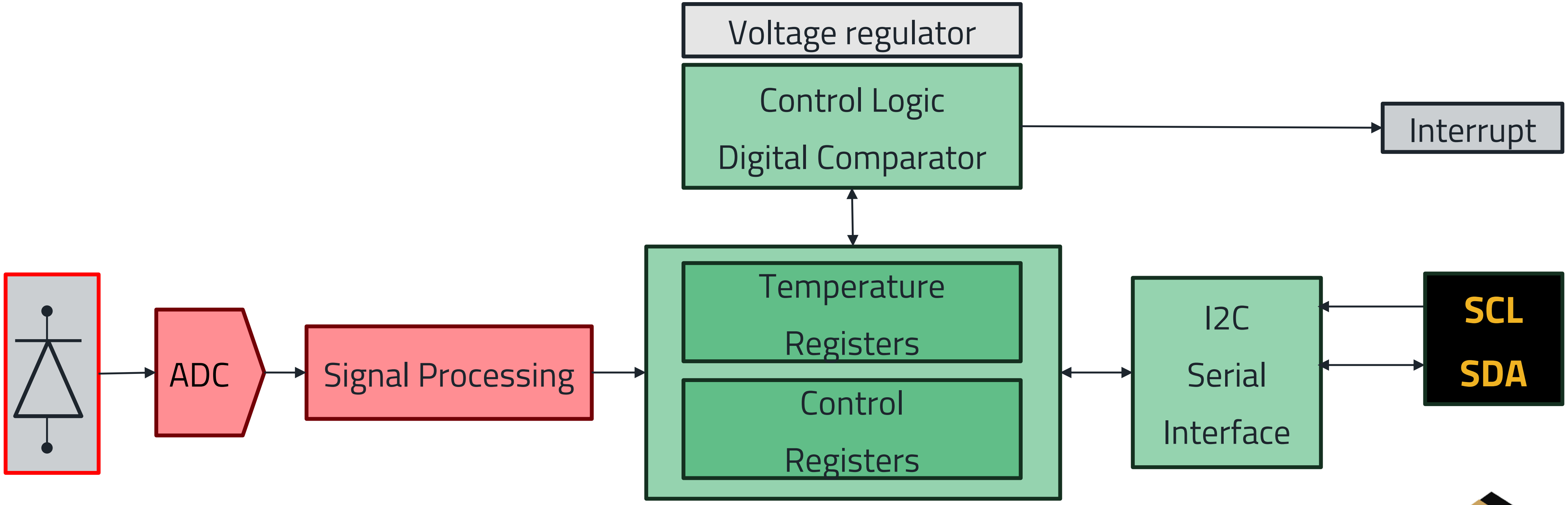




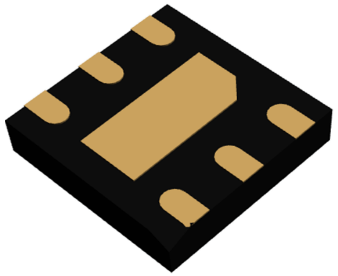


	Thermocouple	RTD	Thermistor	Semiconductor IC based
Measurement range	-250 °C to 2500 °C	-250 °C to 700 °C	-100 °C to 250°C	-55°C to 150°C
Accuracy	Average (require CJC)	Highest	Average	High
Sensitivity	Low-average	Average	High	High
Linearity	Average	Good	Low	Highest
Peripheral Circuits/Calibration	CJC; Amplifier; Scaling	Resistance correction; Scaling	Scaling	No
Footprint	Large	Medium	Small	Smallest
Price	Moderate	Very high	Low	Low

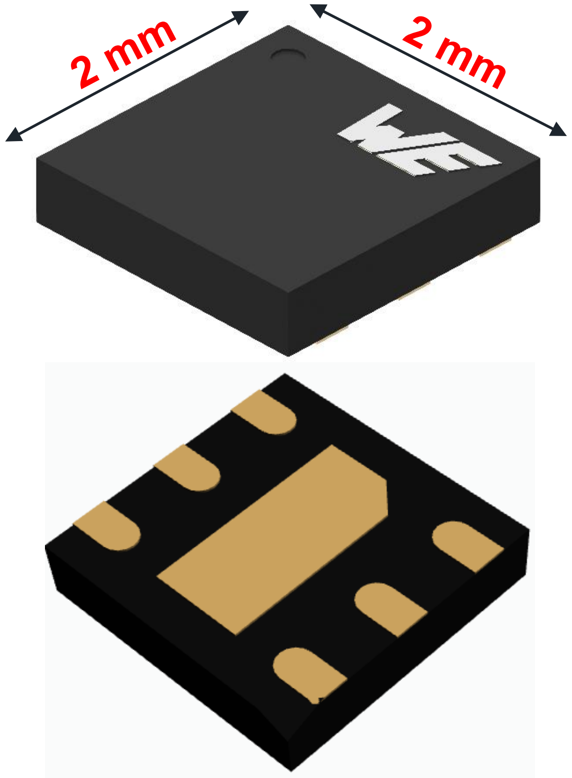
WSEN-TIDS: Block Diagram



- ✓ Si based diode (BJT) + digital logic → Single **ASIC**
- ✓ Factory calibrated output
- ✓ No peripharal circuits



TIDS - Temperature Sensor: Technical Features



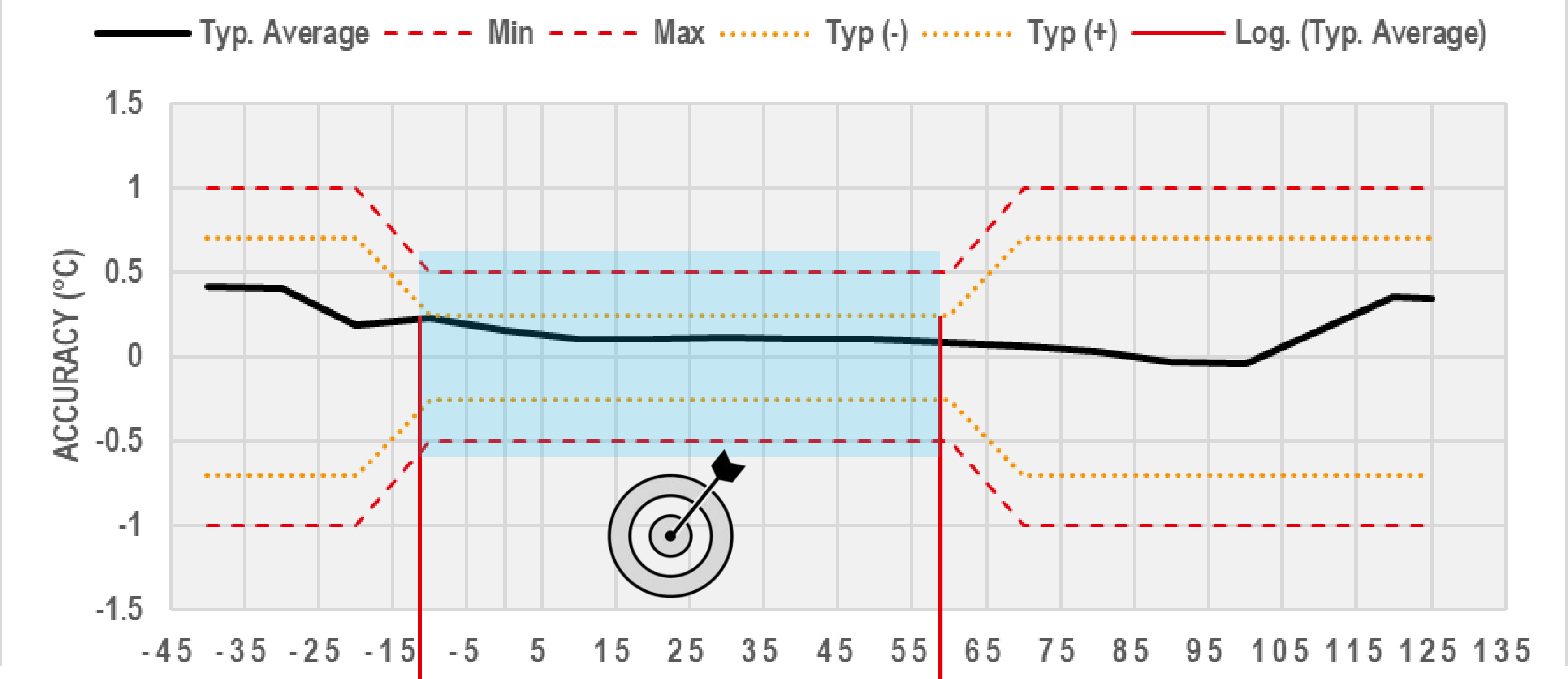
- ✓ Compact 2 x 2 x 0.5 mm package
- ✓ Temperature Range: **-40° to +125°C**
- ✓ Accuracy: **±0.25°C** (typ.) / ±0.5°C (max)

- ✓ 16 bit Output resolution
- ✓ Low voltage: 1.5 to 3.3 Volts
- ✓ Ultra-Low Current Consumption: **1.75 µA / 0.6 µA**

- ✓ Exposed pad at the bottom
- ✓ Fully calibrated during production
- ✓ Most importantly in stock

https://www.we-online.com/catalog/en/WSEN-EVAL_TIDS

WSEN-TIDS ACCURACY



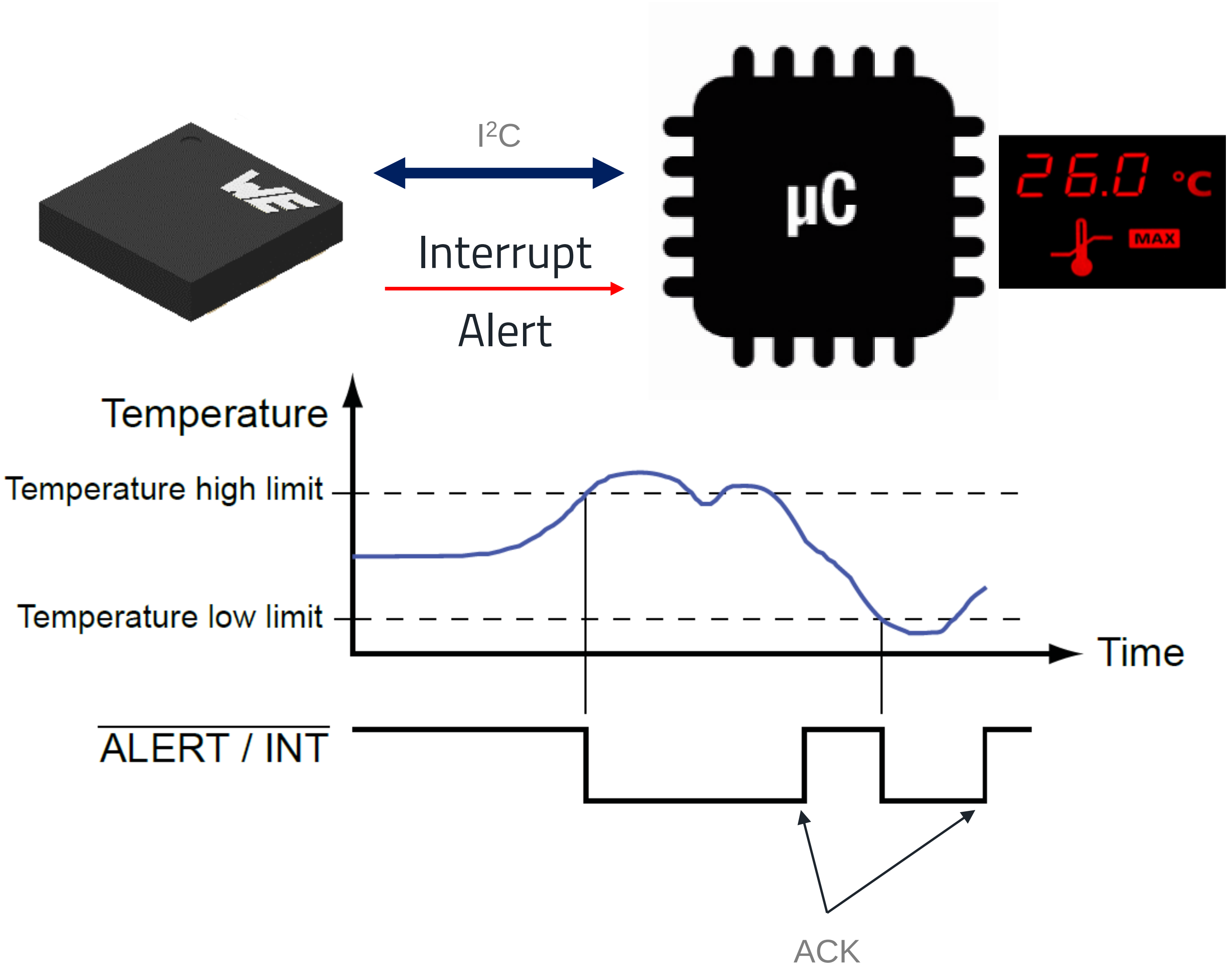
-10°C to 60 °C

Typ = ± 0.25 °

Min/max = ± 0.5 °C

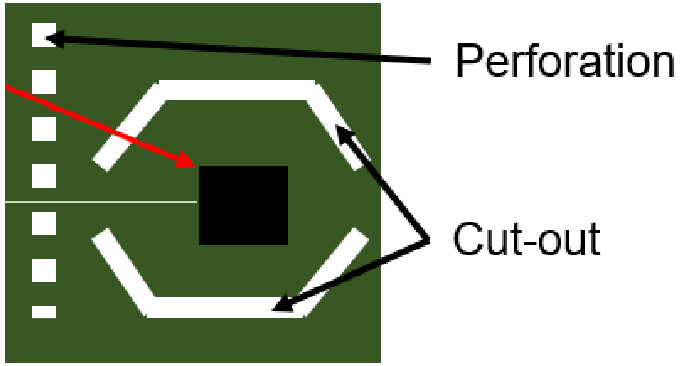
TIDS to MCU Interface:

- ✓ Digital I2C serial interface
- ✓ Two selectable address
- ✓ Single conversion
- ✓ Continuous o/p
- ✓ 25 to 200 Hz ODR
- ✓ 40ms to 5ms refresh rate
- ✓ Interrupt output
  - ✓ Temperature high
  - ✓ Temperature

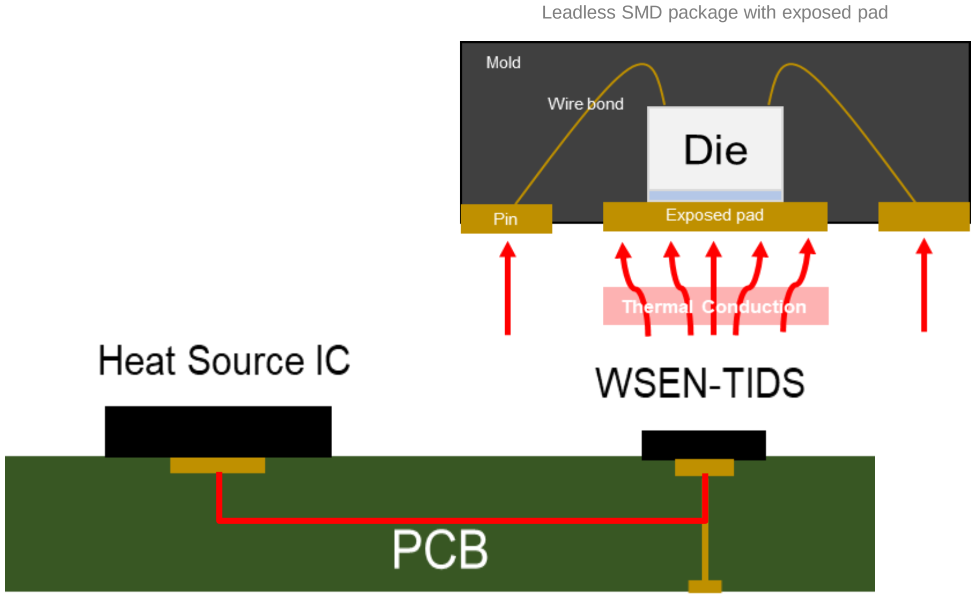


TIDS - Temperature Sensor: Structure + Applications:

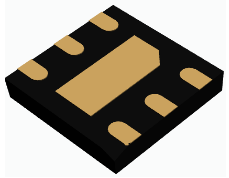
- ✓ Automatic Fan control
- ✓ Highly accurate PCB temperature monitoring…
- ✓ Highly accurate air temperature measurement
- ✓ Constant Temperature crystal Oscillators



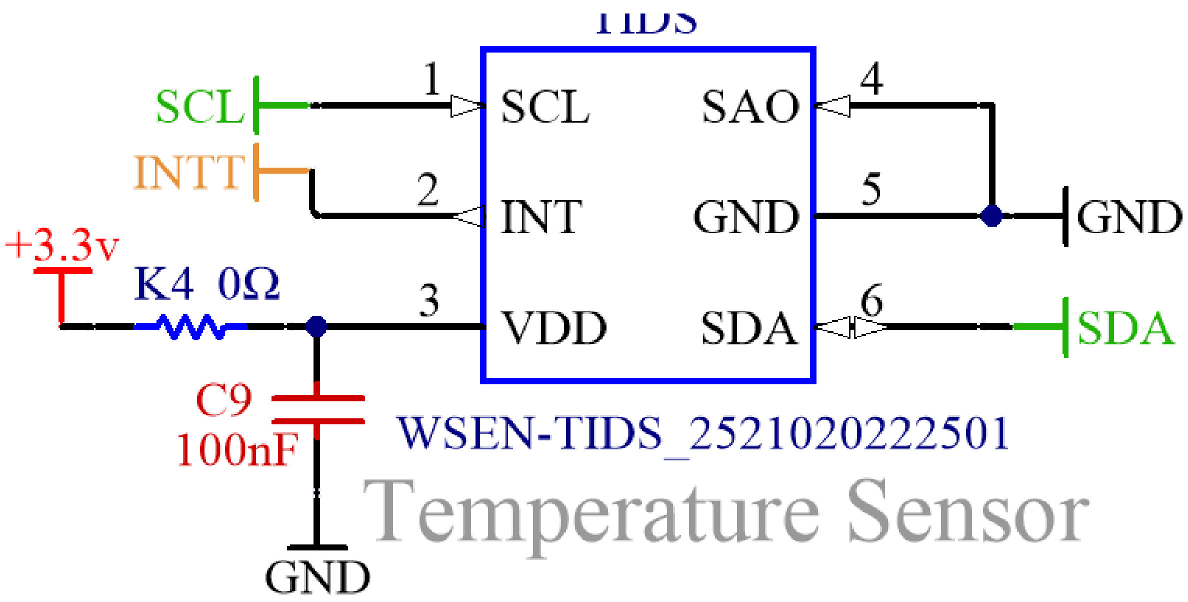
Ambient Temperature Sensing



PCB Heat Sensing



TIDS – Temperature Sensor: Schematic and PCB Recommendations:

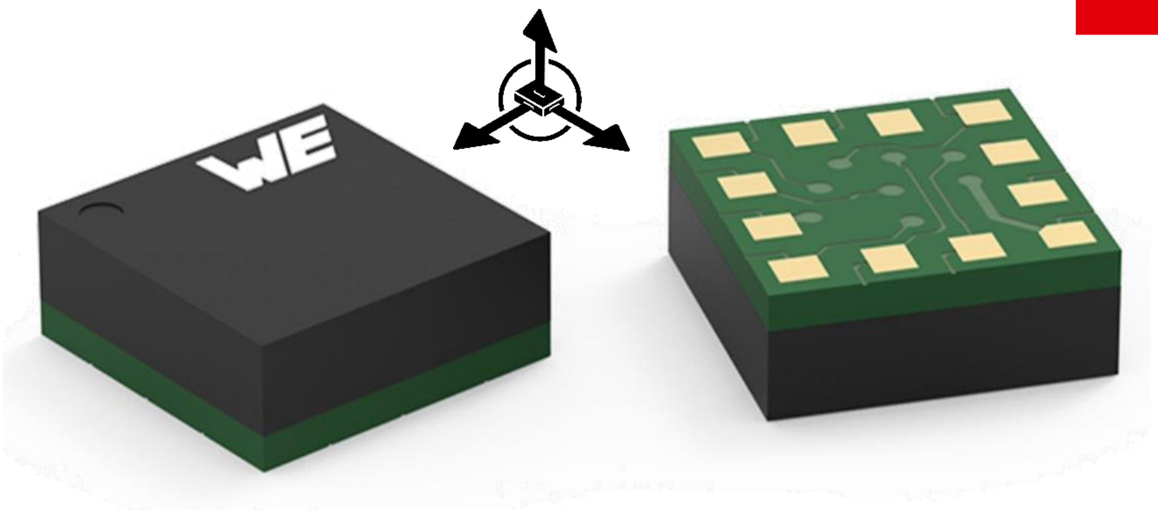


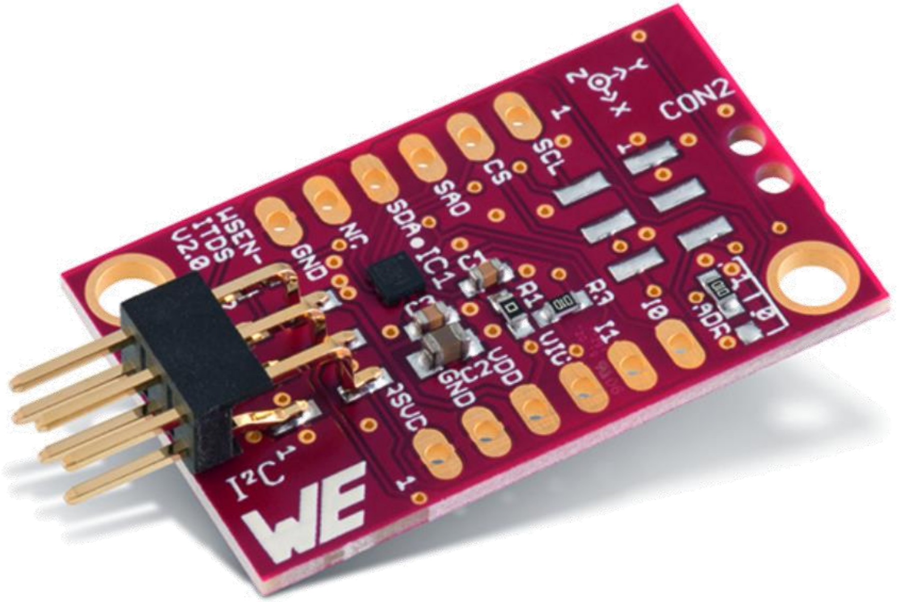
- SAO may be used to alter I2C address
- K4 - 0Ω link can be used to measure sensor current
- K4 could also be replaced with ferrite bead
- Decoupling capacitor is recommended for EMI (C9)
- I2C may require pull-up resistors ~ 10KΩ

Firmware Example:

```
float temperature = sensor.read_temperature();
Serial.print(temperature);
```

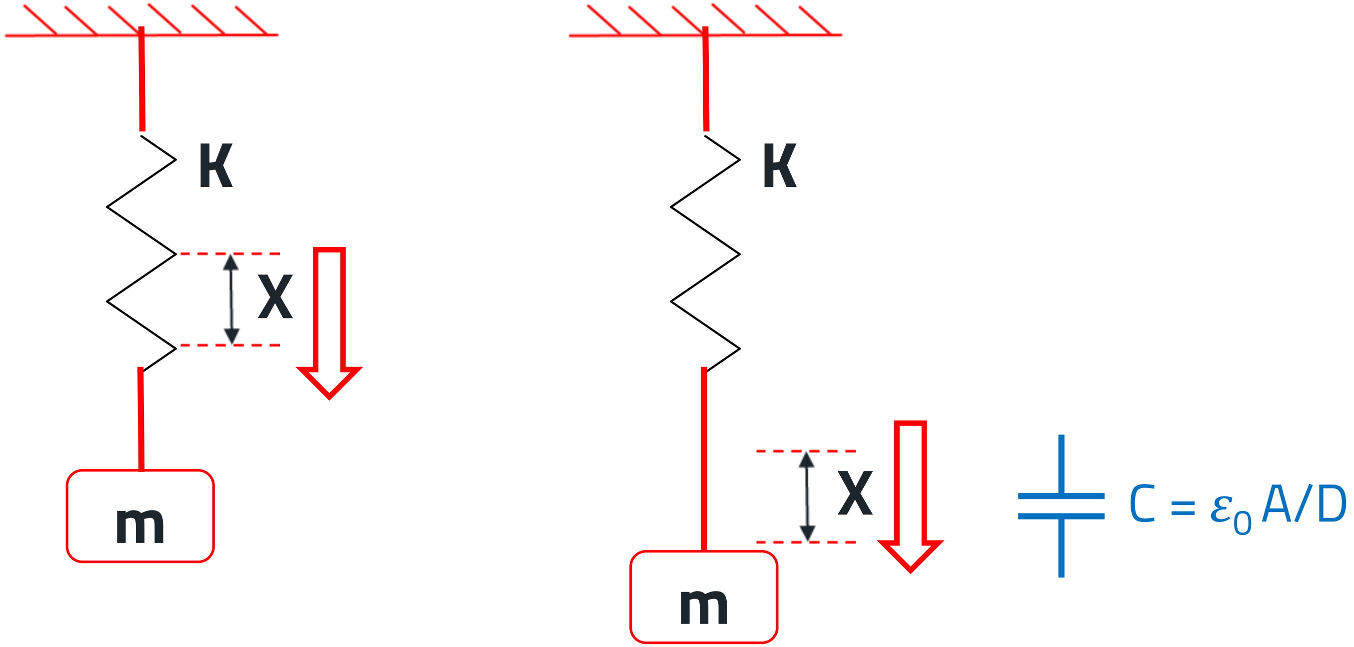
ACCELERATION SENSOR





https://www.we-online.com/catalog/en/WSEN-EVAL_ITDS

Basic Principle of Acceleration Sensor:



Hooke's Law:
F = KX

Newton's Second Law:
F = ma

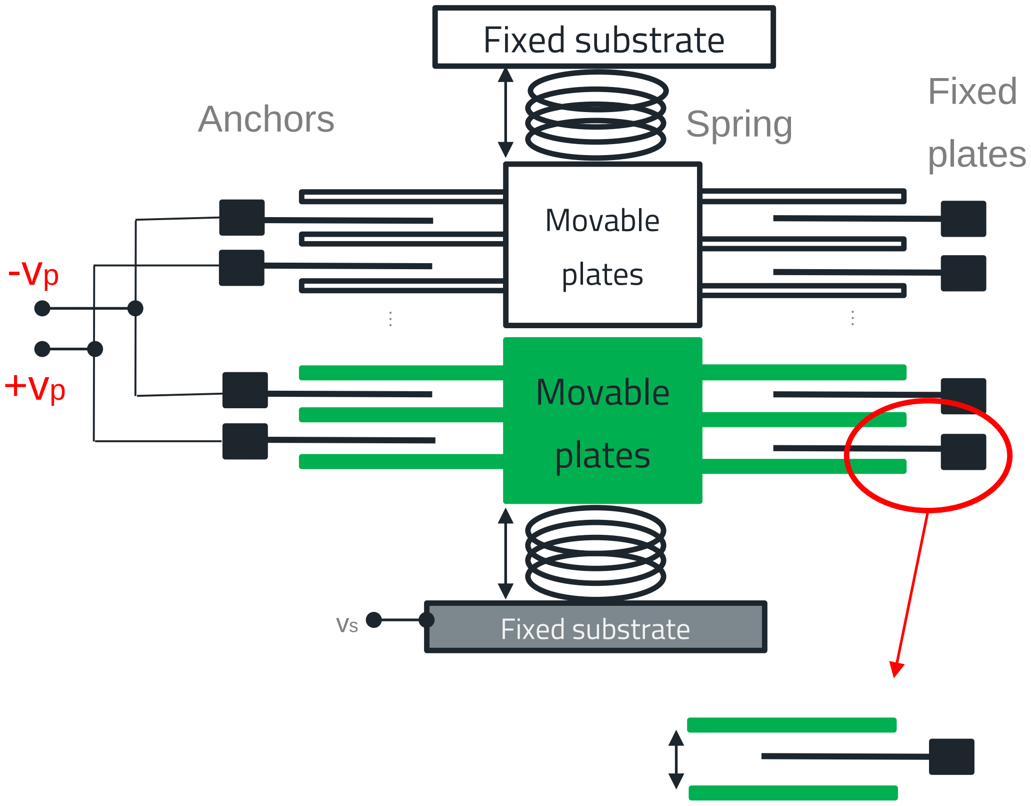
F = KX
F = ma

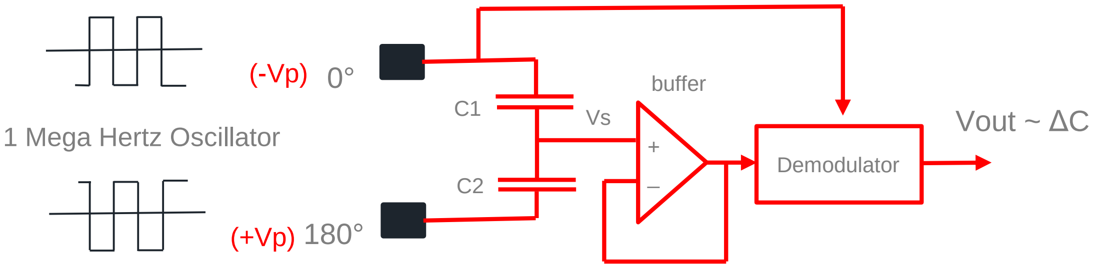
So, acceleration:
A = KX/M
A = change in capacitance

K = Tensile (spring) constant
X = Displacement of spring
m = mass of the object
a = acceleration

ε_0 = Dielectric constant
A = Area of the capacitive plates
D = distance between plates

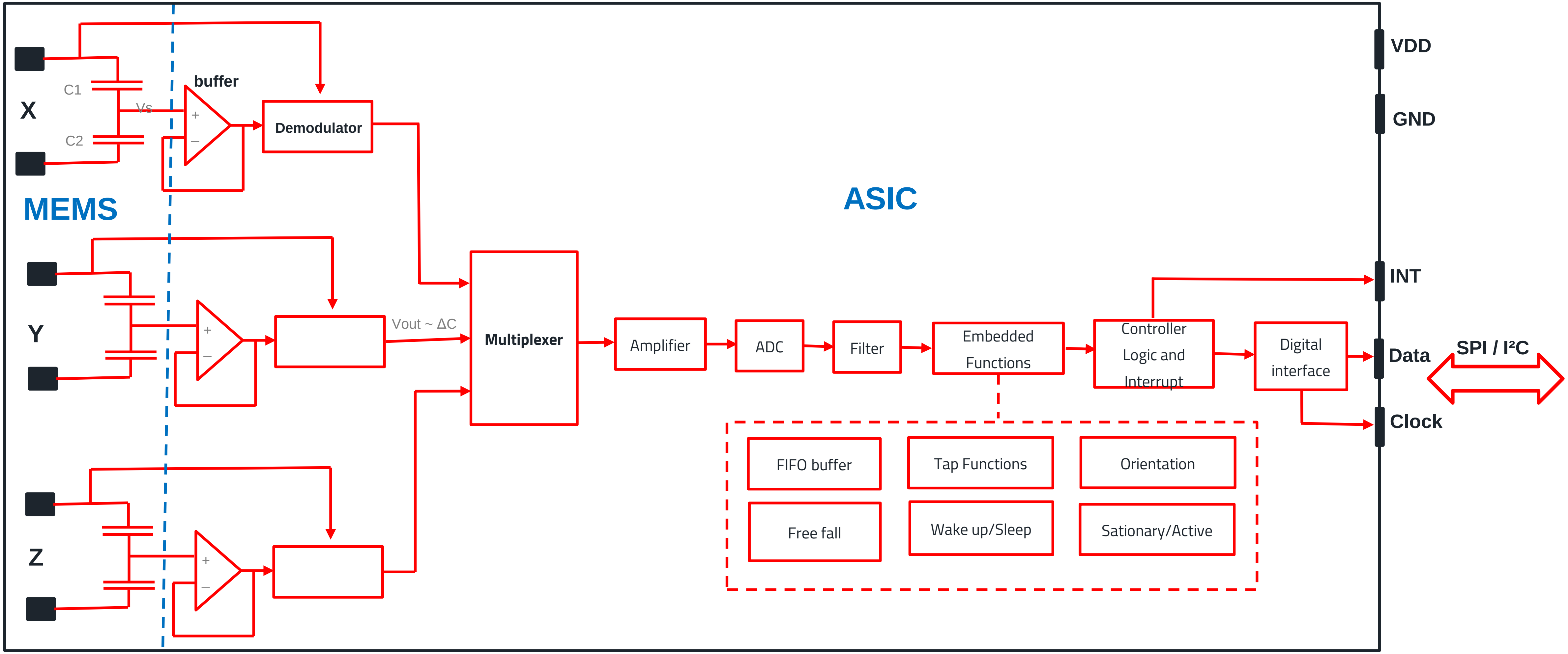
Basic Principle of MEMS Sensor:



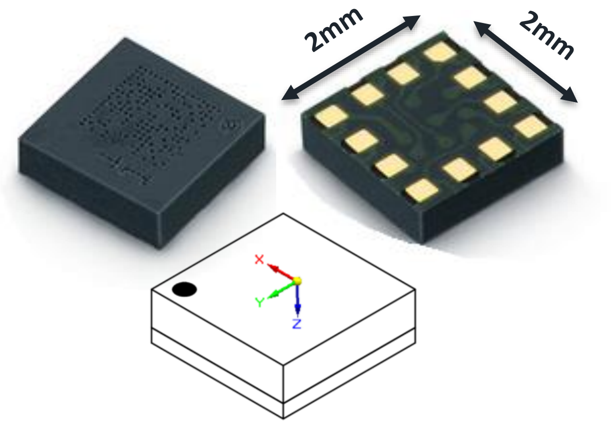


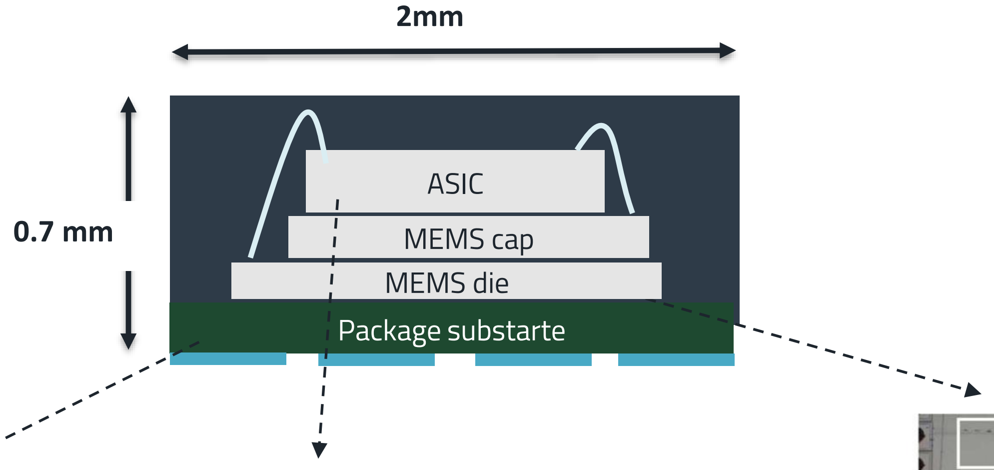
MEMS: Micro-Electro Mechanical System

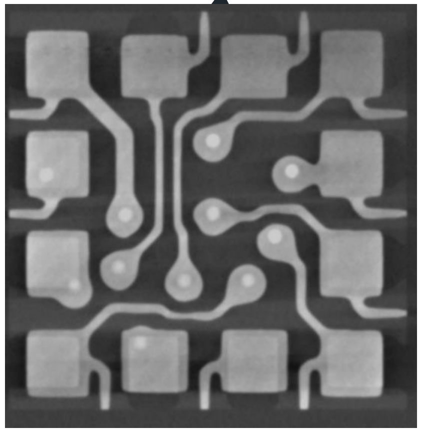
ITDS – 3 axis acceleration sensor (accelerometer)

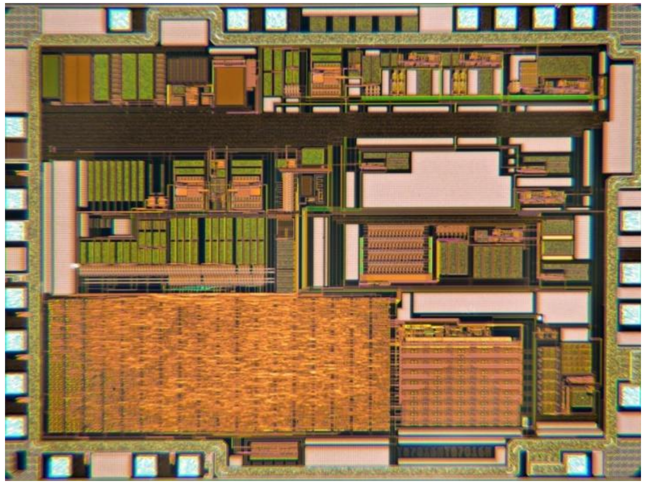


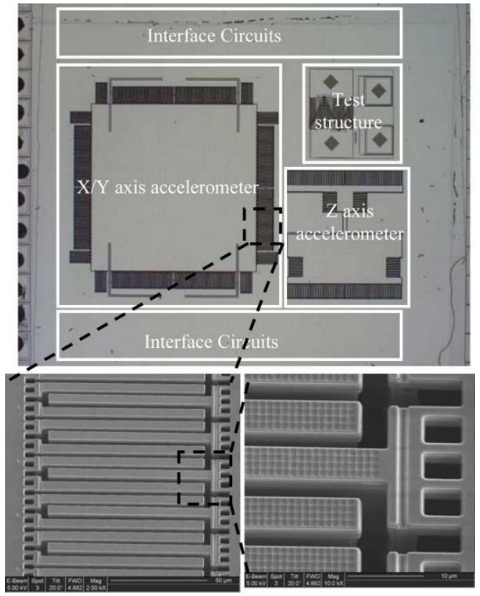
MEMS – capacitive acceleration sensor: internal structure







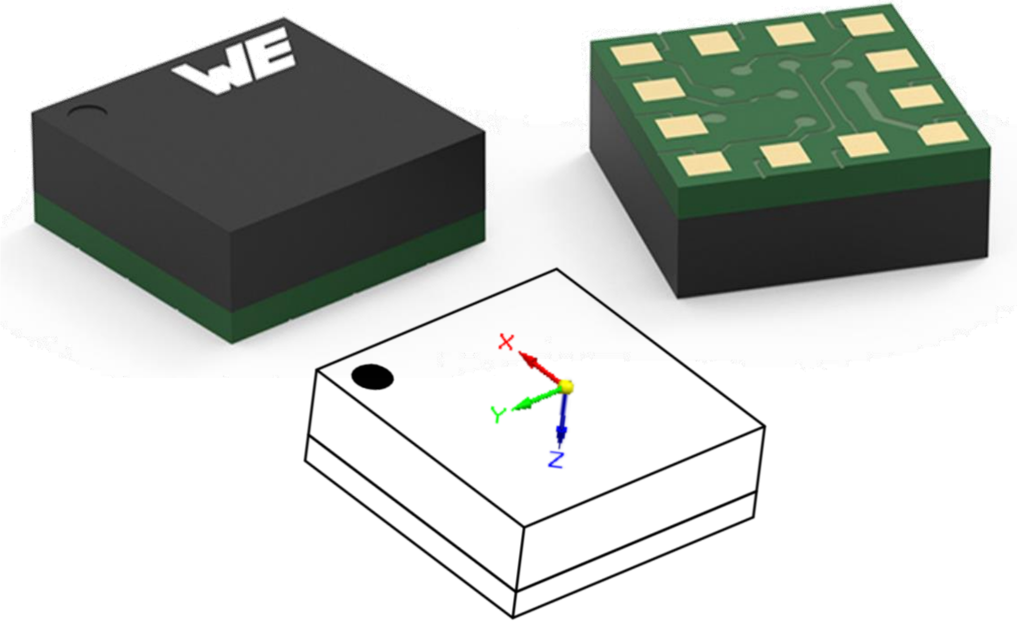




https://www.ims.fraunhofer.de/de/Geschaeftsfelder/Biohybrid-Systems/Anwendungen/Multisensor-System.html

Sun, Hongzhi, et al. "A Low-Power Low-Noise Dual-Chopper Amplifier for Capacitive CMOS-MEMS Accelerometers." *IEEE Sensors Journal*, vol. 11, no. 4, 2011, pp. 925–933., doi:10.1109/jsen.2010.2064296

ITDS – Technical Features of Accelerometer



MEMS based capacitive sensing principle

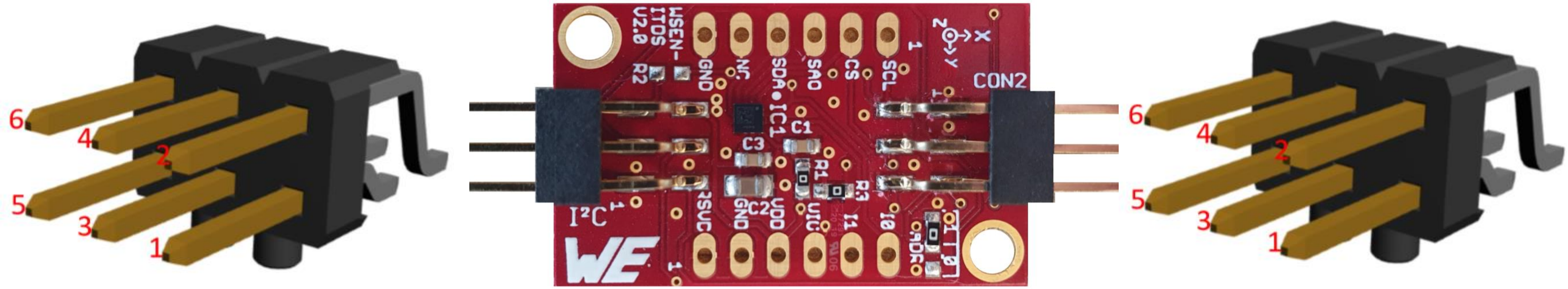
Integrated Temperature Sensor

I²C and SPI digital interface

https://www.we-online.com/catalog/en/WSEN-EVAL_ITDS

- ✓ 2 x 2 x 0.7mm
- ✓ 1.7v to 3.6v
- ✓ -40 °C up to +85 °C
- ✓ 32 level FIFO buffer
- ✓ 100nA sleep current
- ✓ 16µA to 155µA operating current
- ✓ ODR up to 1600, 400Hz
- ✓ Full scale ±2 g, ±4 g, ±8 g, ±16 g
- ✓ Max acceleration = 3000 g
- ✓ Drift with Temperature = ±2 mg/ºC
- ✓ Thermal accuracy = ±15 ºC
- ✓ Free fall offset = ±30 mg
- ✓ Sensitivity / accuracy ±3 %
- ✓ Low Noise Density – 90 µg√Hz
- ✓ 2 x Interrupts = Free-fall, wake-up, tap, activity, motion and orientation detection

ITDS – Accelerometer Eval board



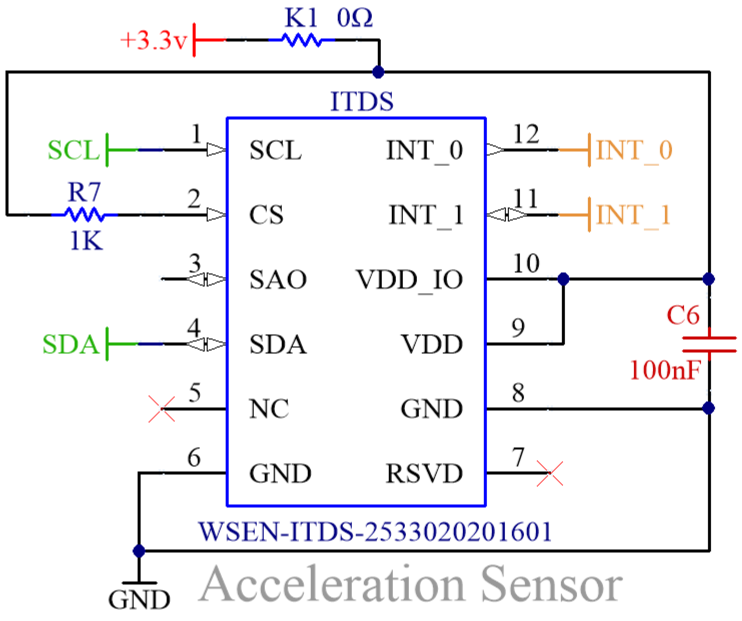
Pin No	I^2C Pins (CON1)
1	*GND*
2	*SCL*
3	*SDA*
4	*GND*
5	*NC*
6	*VDD*

I2C Address = 0011 001b = 0x31

Pin No	SPI Pins (CON2)
1	*GND*
2	*SCL*
3	*SDA (MOSI)*
4	*CS*
5	*SAO (MISO)*
6	*VDD*

SPI = remove R3 and ADR resistors

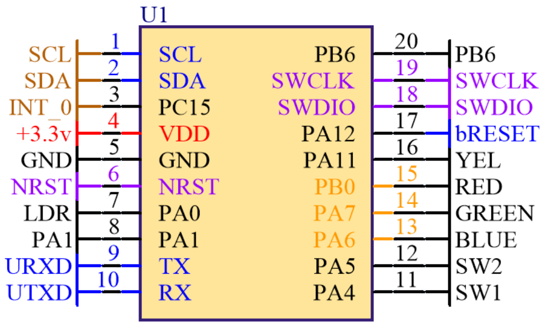
ITDS – Accelerometer to MCU Interface



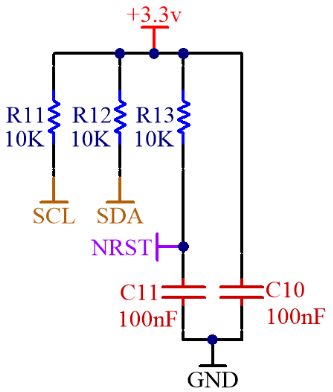
Acceleration Sensor

SAO pin is for **I2C** address selection or SPI SDO

Interrupts and external pull-up resistors are optional, depends on the MCU type.

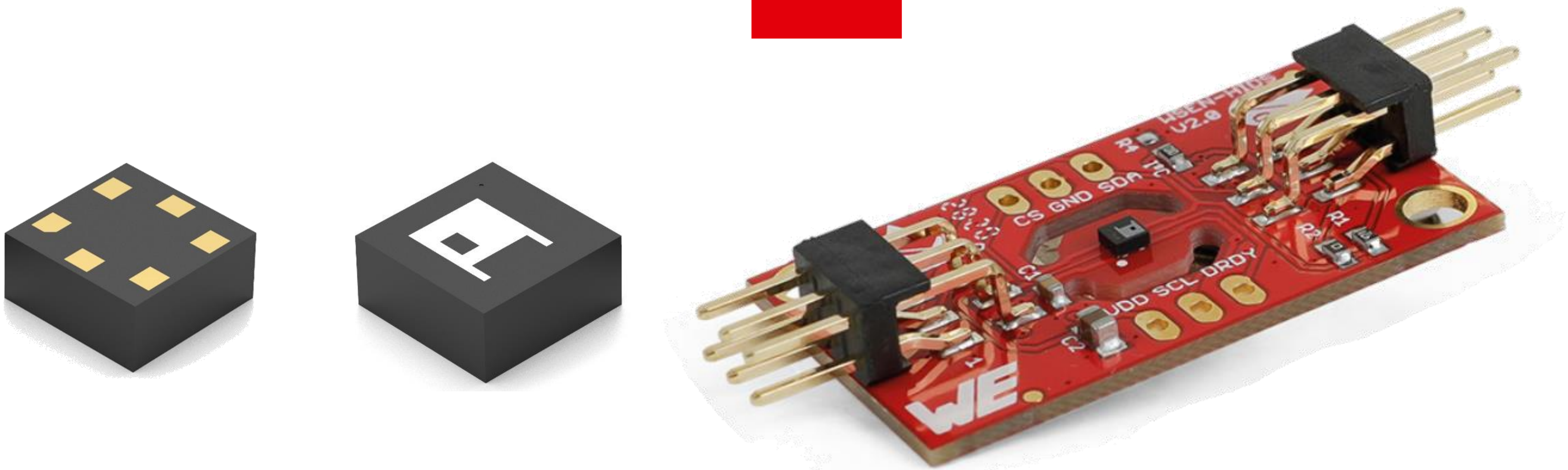


Microcontroller



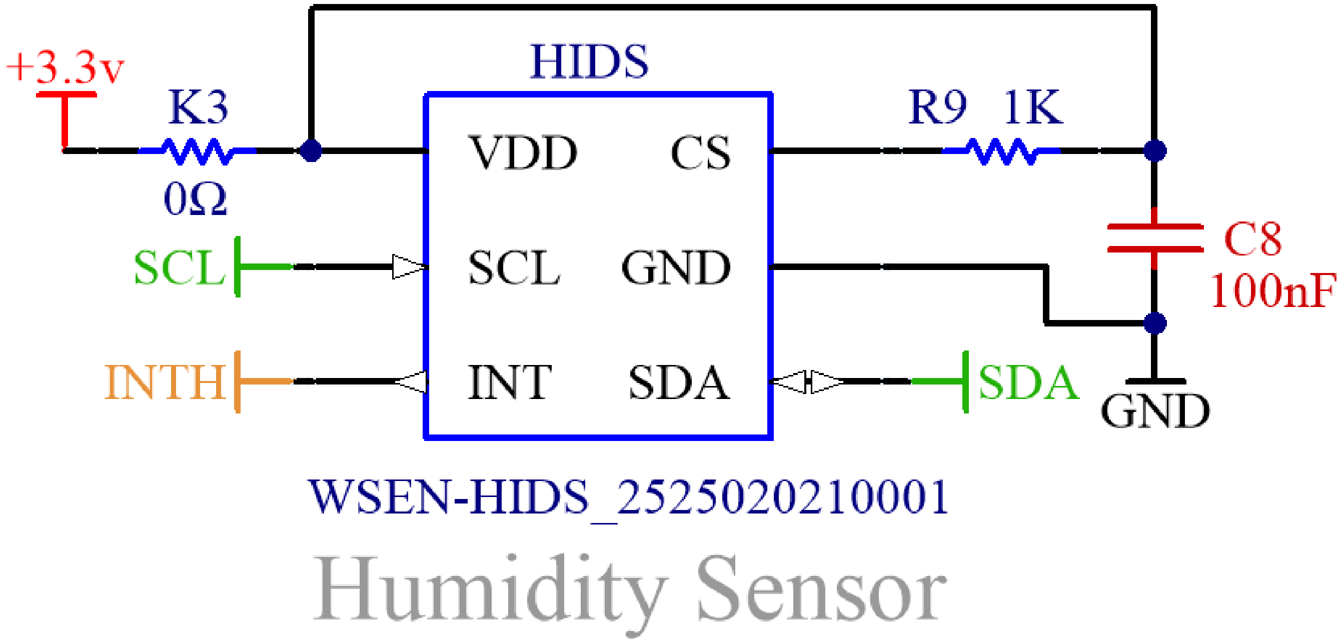

```
void readAcclerometer()
{
  Wire.beginTransmission (0x19);
  Wire.write (0x28);
  Wire.endTransmission ();
  Wire.requestFrom (0x19,6);
  vxl = Wire.read();
  vxm = Wire.read();
  vyl = Wire.read();
  vym = Wire.read();
  vzl = Wire.read();
  vzm = Wire.read();
  vx = ((vxm <<8) | ( vxl & 0xFF));
  vy = ((vym <<8) | ( vyl & 0xFF));
  vz = ((vzm <<8) | ( vzl & 0xFF));
}
```

HUMIDITY SENSOR



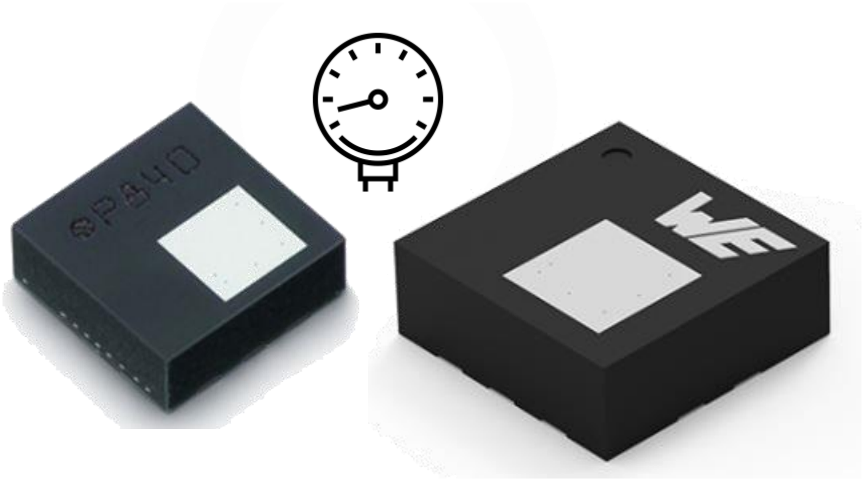
https://www.we-online.com/catalog/en/WSEN-HIDS

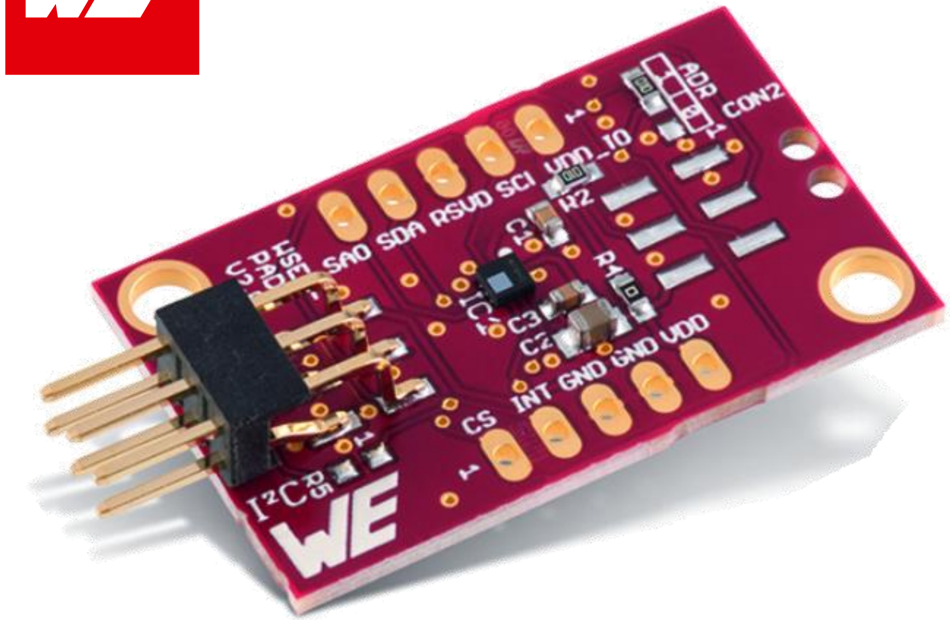
HIDS – Schematic and PCB Guidelines:



- ✓ MEMS based capacitive sensing principle
- ✓ Relative humidity range 0% to 100%
- ✓ Calibrated 16 bit humidity and temperature output
- ✓ I²C and SPI communication
- ✓ Output data rate up to 12.5 Hz
- ✓ Operating temperature range: -40 °C to 120 °C

ABSOLUTE PRESSURE SENSOR





https://www.we-online.com/catalog/en/WSEN-PADS

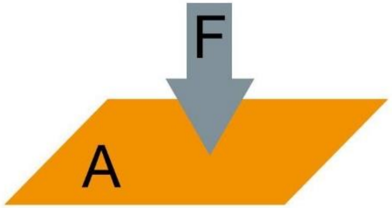
Pressure basics

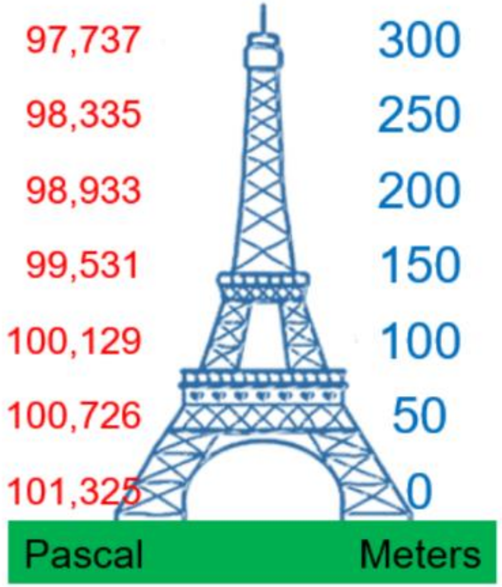
1 Newton force applied on an area of 1 meter^2 exerts Pressure of 1 Pascal (N/m^2) = 0.01 mbar

Vacuum = 0 bar
Atmosphere = 996mbar ~ 1bar

0.01 mbar = 1 pa
1mbar = 100 pa
1 bar = 100,000pa = 100 kpa

$$Pressure\ (p) = \frac{Force\ (F_n)}{Area(A)}$$

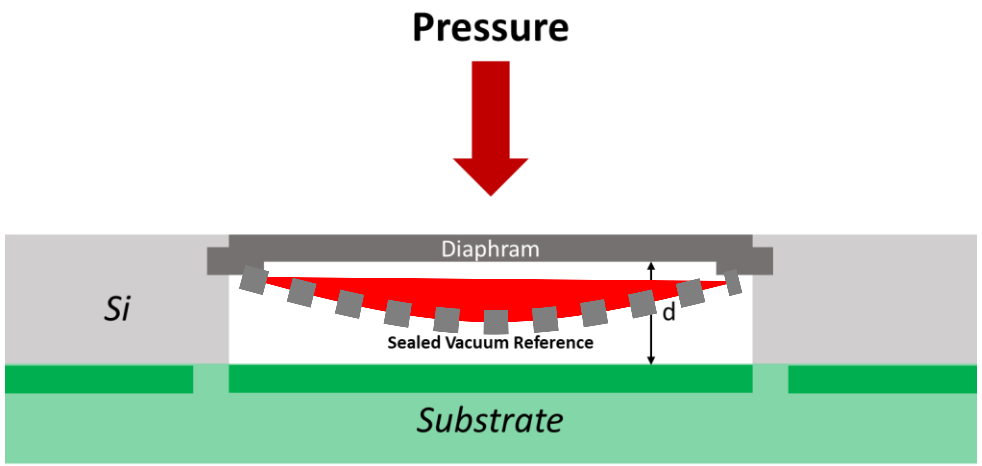




Pressure Sensor can be…

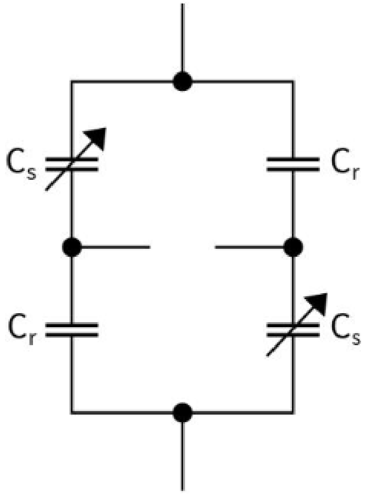
- Optical
- Piezo electric
- Piezo resistive
- Magnetic
- Membrane
- Capacitive
- MEMS based

Capacitive MEMS – Pressure sensor



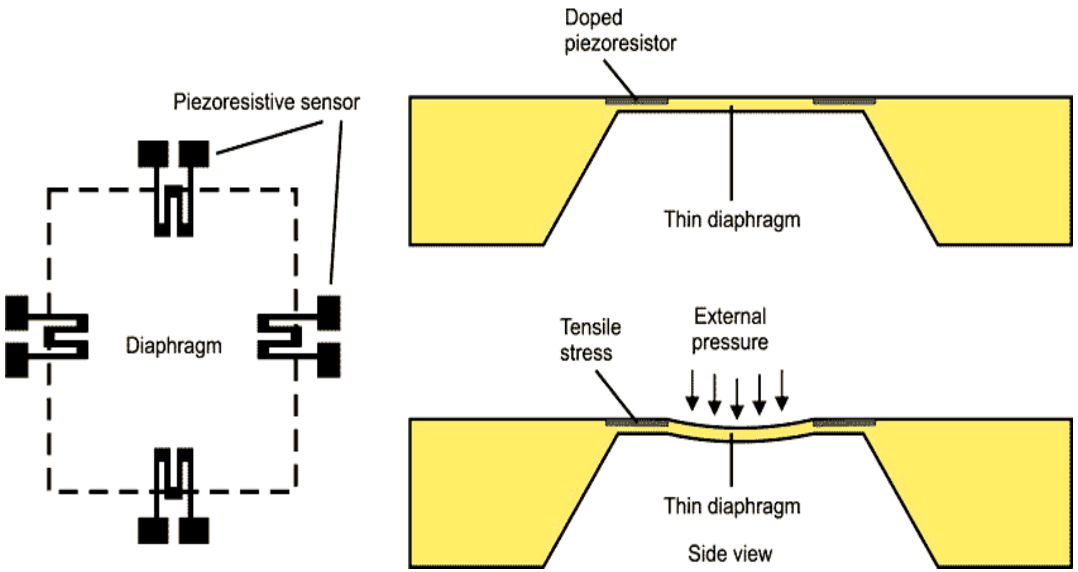
$$C = \varepsilon_0 \varepsilon_r \frac{A}{d}$$

Wheatstone Bridge Configuration:

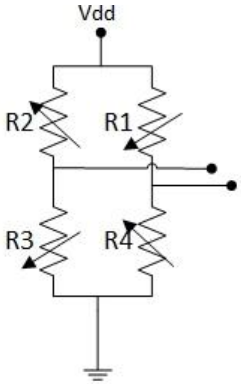


- ✓ Less thermal drift
- ✓ Tolerant to short-term over pressure
- Ø Non-linear o/p
- Ø Low SNR
- Ø Low dynamic range
- Ø Hard to manufacture

Piezo Resistive – Pressure sensor

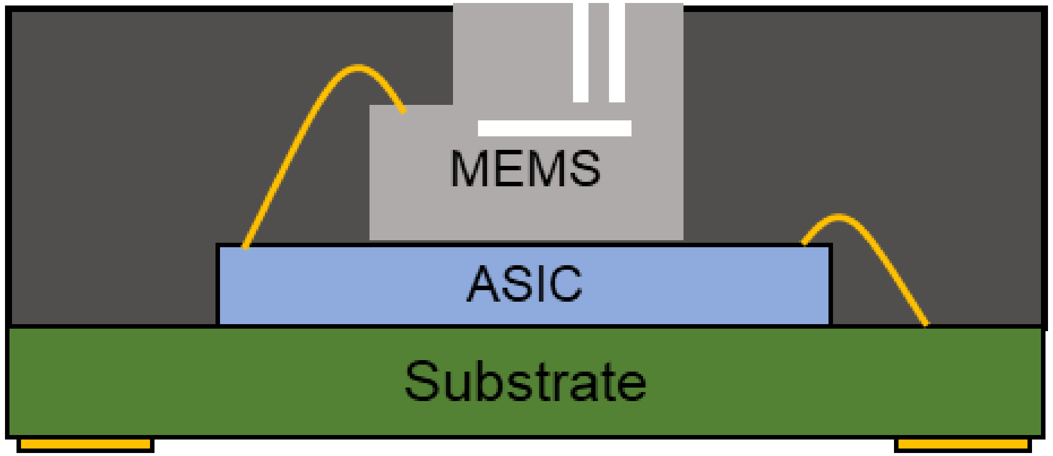


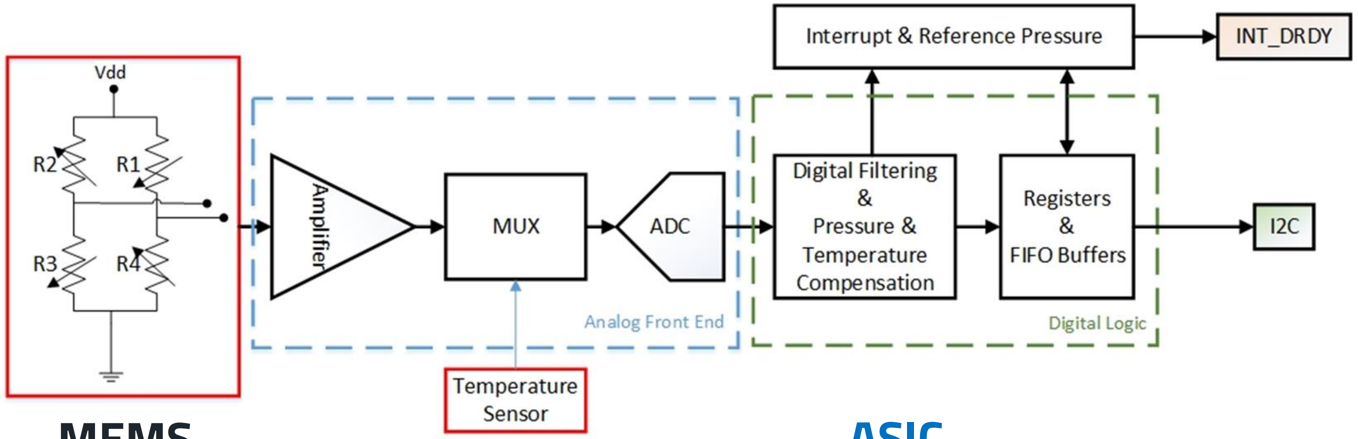
https://www.radiolocman.com/review/article.html?di=148185



- ✓ Very linear result
- ✓ Easy to produce
- Ø Sensitive to temperature
- Ø Need frequent calibration

PADS – MEMS Based Absolute Pressure Sensor





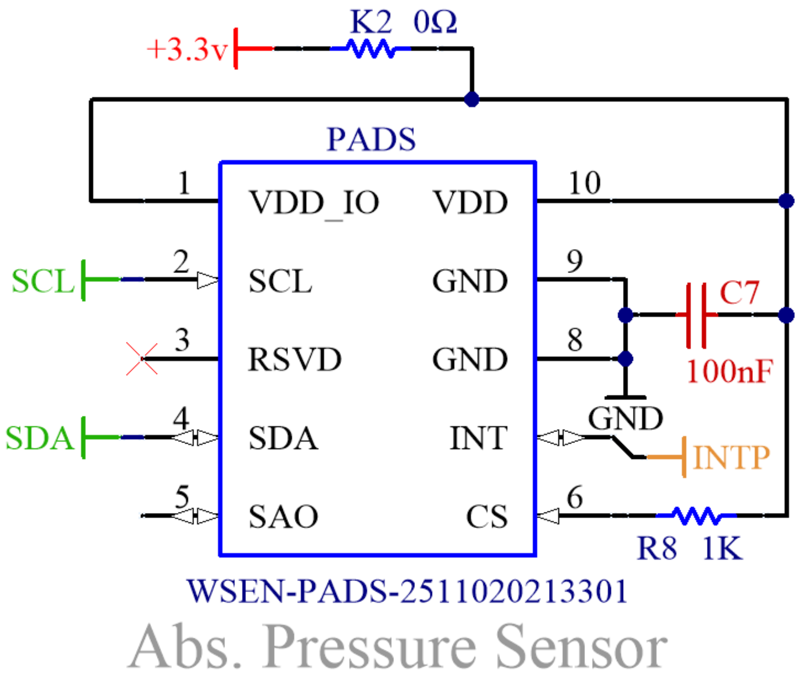
MEMS **ASIC**

PADS – MEMS

- Increased robustness
- Reduced contamination risk
- Best moisture and dust resistance
- Multiple vent capillaries
- Factory calibrated at multiple temp.
- Calibration values stored locally

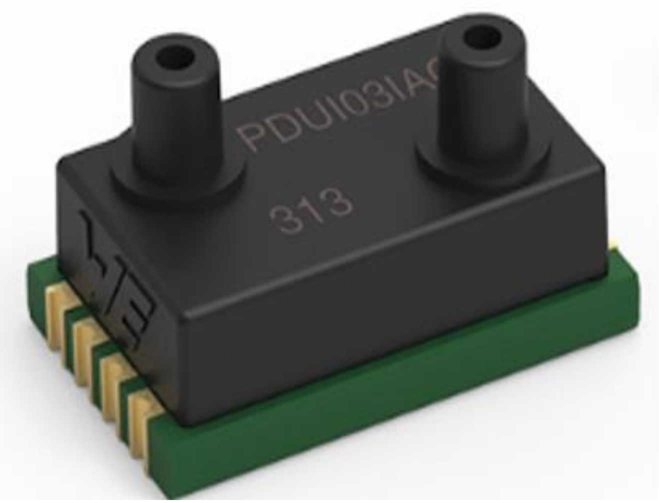
PADS – Schematic and Firmware:

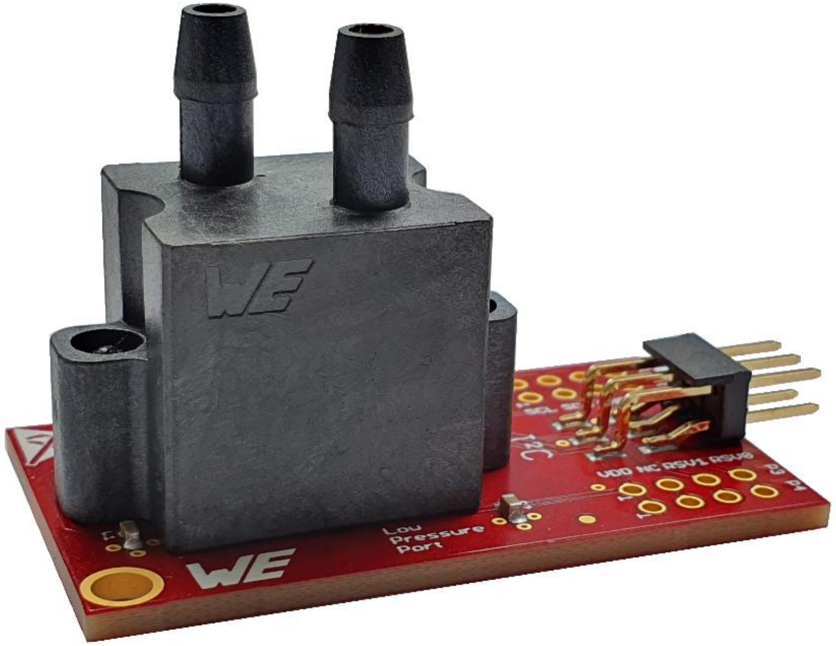
```
void readPADS(){ // STM32 IDE
///  https://www.we-online.de/catalog/en/WSEN-PADS
//static const uint8_t padsAddress = 0x5D <<1;
//static const uint8_t padsAddress = 0x5C <<1;
iBuf[0] = 0x28;
uint8_t ret = HAL_I2C_Master_Transmit(&hi2c1, padsAddress, iBuf, 1, HAL_MAX_DELAY);
  if( ret != HAL_OK){ beep; } // error beep, if sensor is removed.

  iBuf[0] = 0x28;
  ret = HAL_I2C_Master_Receive(&hi2c1, padsAddress, iBuf, 6, 50);

   uint8_t p1, p2, p3;
   p1 = iBuf[1];
   p2 = iBuf[2];
   p3 = iBuf[3];
   padsT1 = iBuf[3];
   padsT2 = iBuf[4];
   padsTemp = (padsT1 + padsT2*256)*0.01;

   uint32_t int32, mb;
   int32    = p3*65536 + p2*256 + p1;
   mb        = int32/4096;        // Hectopascle = mBar
   mBarLsb   = 0x00FF & mb;
   mBarMsb   = mb >> 8;
}
```



- ✓ FIFO buffer
- ✓ 26 to 126 kPa range
- ✓ 900 nA sleep current
- ✓ 1.7 to 3.6v DC voltage
- ✓ Built in thermometer
- ✓ ±1.5 ºC temp accuracy
- ✓ Two I2C address choices
- ✓ 24 bit pressure reading
- ✓ Programmable interrupt
- ✓ 16 bit temperature reading
- ✓ ± 1 mbar absolute accuracy
- ✓ 4 to 12 µA operating current
- ✓ Low noise altitude detection 6-8 cm

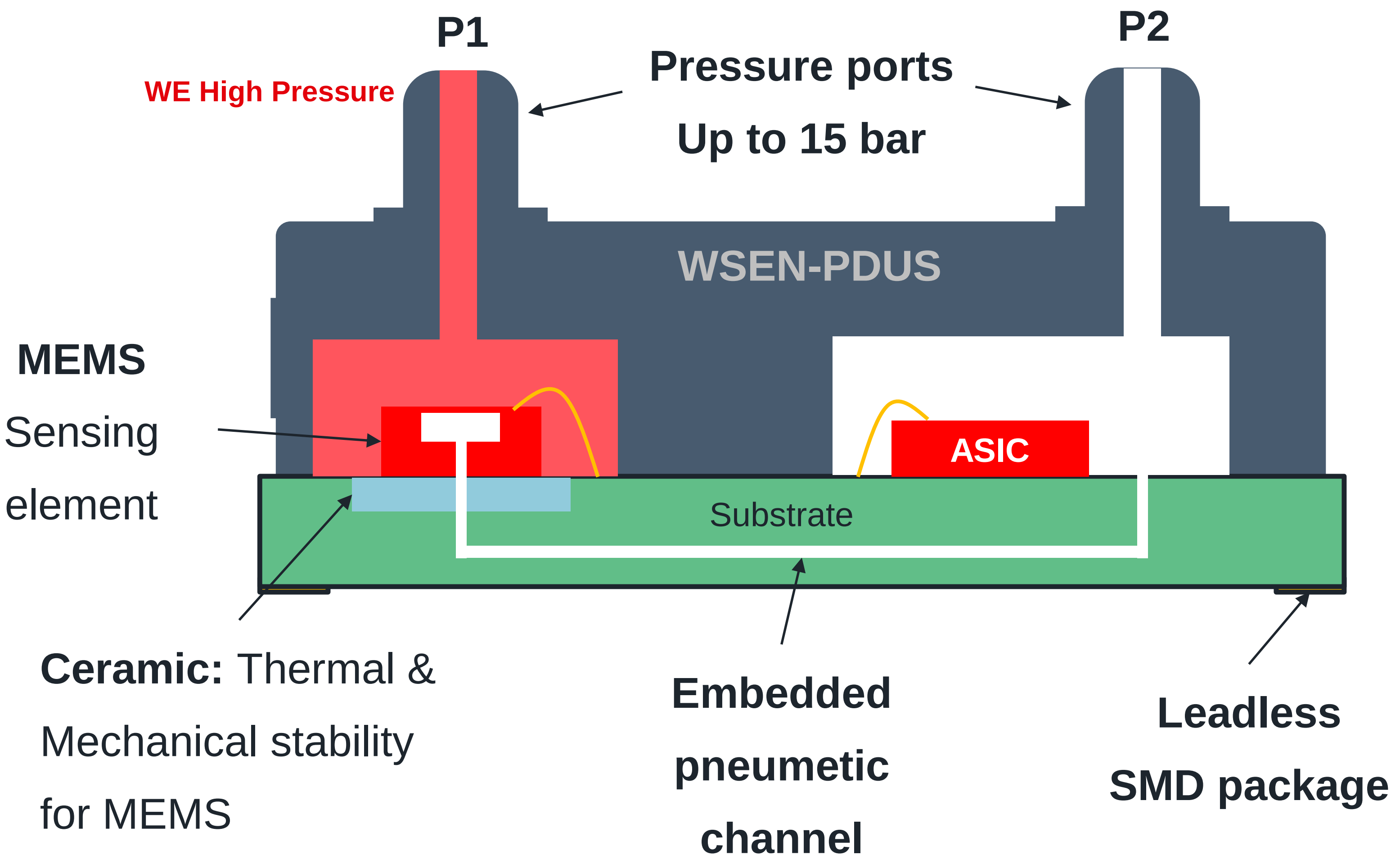
DIFFERENTIAL PRESSURE SENSOR

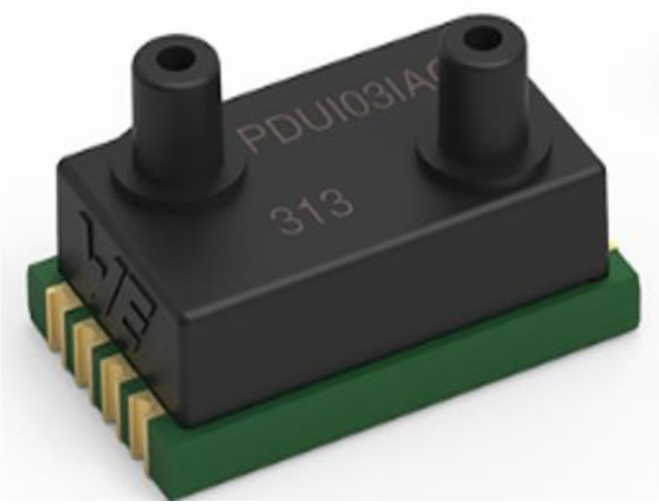


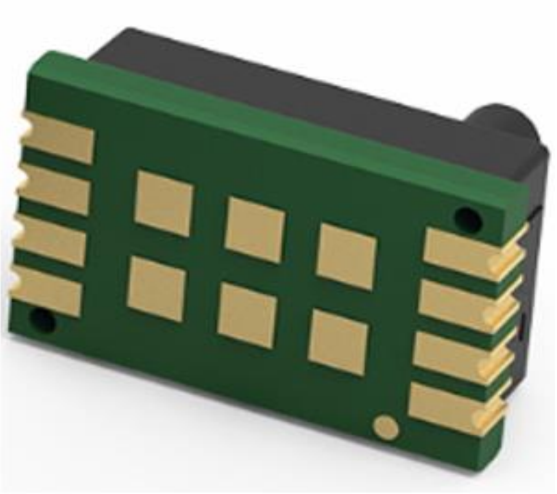


https://www.we-online.com/catalog/en/WSEN-PDUS

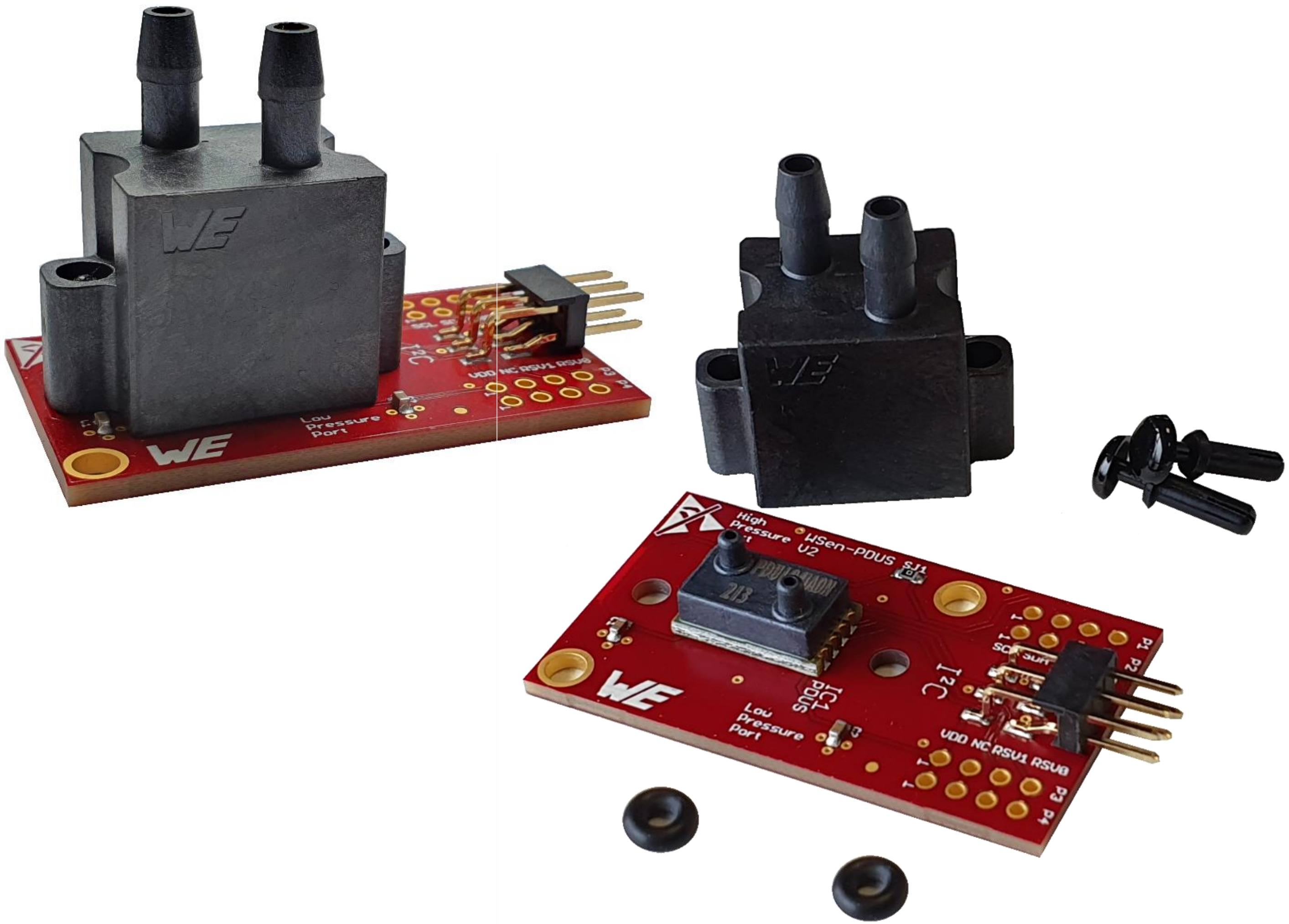
PDUS – MEMS based differential pressure sensor





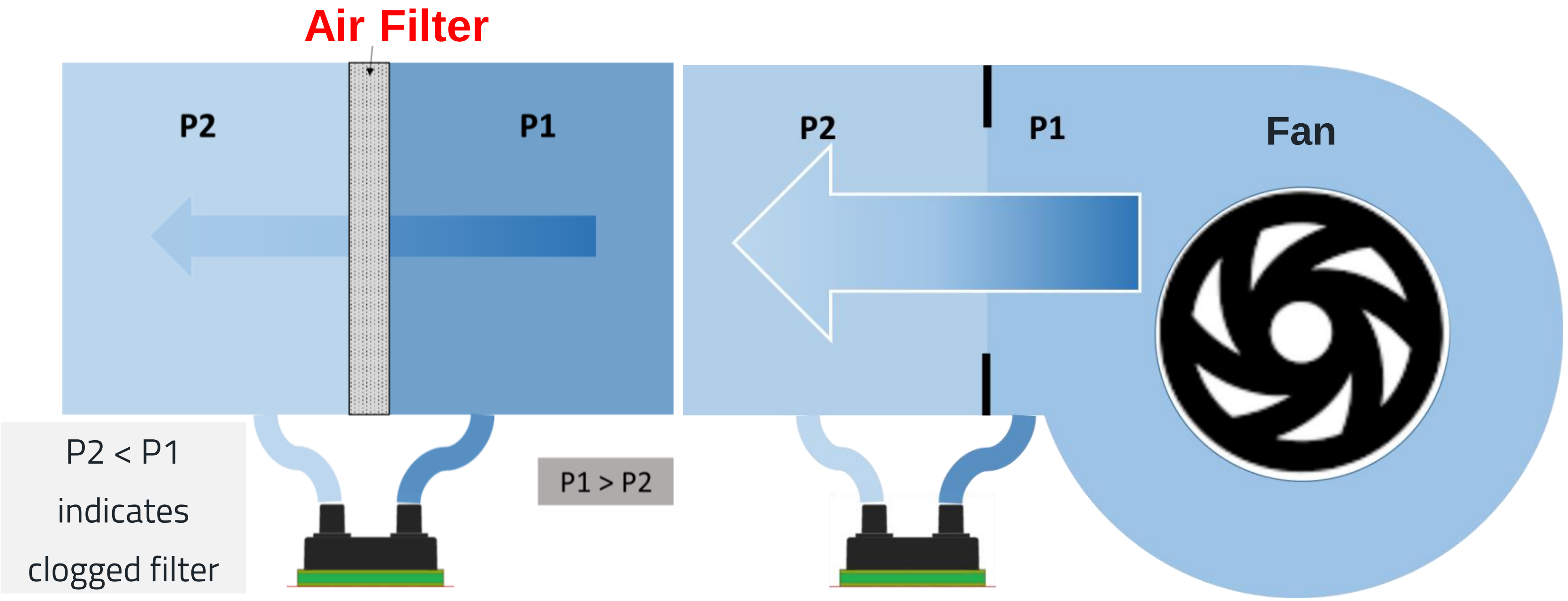


PDUS – Differential pressure sensor eval board:



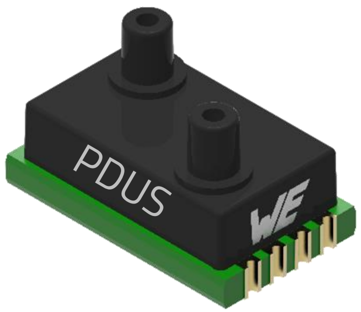
- ✓ 5v operations
- ✓ I2C and Analogue o/p
- ✓ High pressure up to 15 bar
- ✓ 15 bit data
- ✓ Individually calibrated
- ✓ 0 to 70°C compensated
- ✓ Supply (not a ratio metric o/p)
- ✓ 2mm Ø tube connections
- ✓ 4mm Ø adaptor nozzles
- ✓ Best mechanical stability
- ✓ Increased safety
- ✓ CAD files for customisation

PDUS – Application, HVAC filter monitor



Air Filter Monitoring

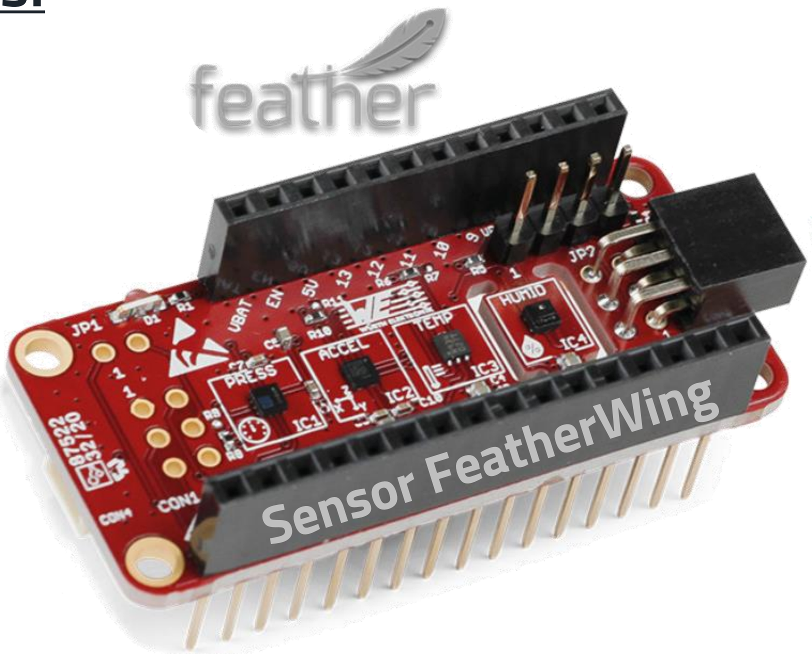
Ventilator & Fan Monitoring



Differential Pressure Sensor

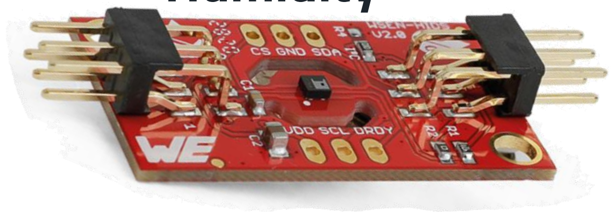
Sensor Experiment Tools:

Free samples of actual sensors
Free tech support
FeatherWings + Shield
Eval boards
GitHub Libraries
Altium, Eagle, STP Libraries
Code Examples PIC, ARM, Arduino, STM32 etc.

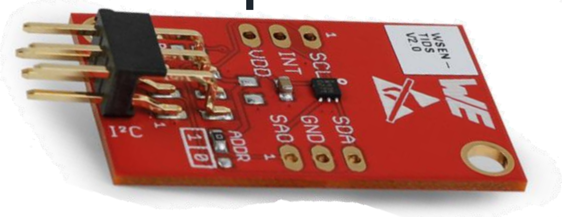


Arduino Uno Sensor Shield

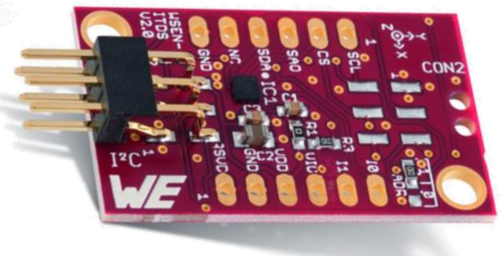
Humidity



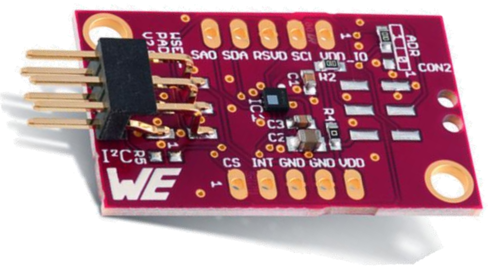
Temperature



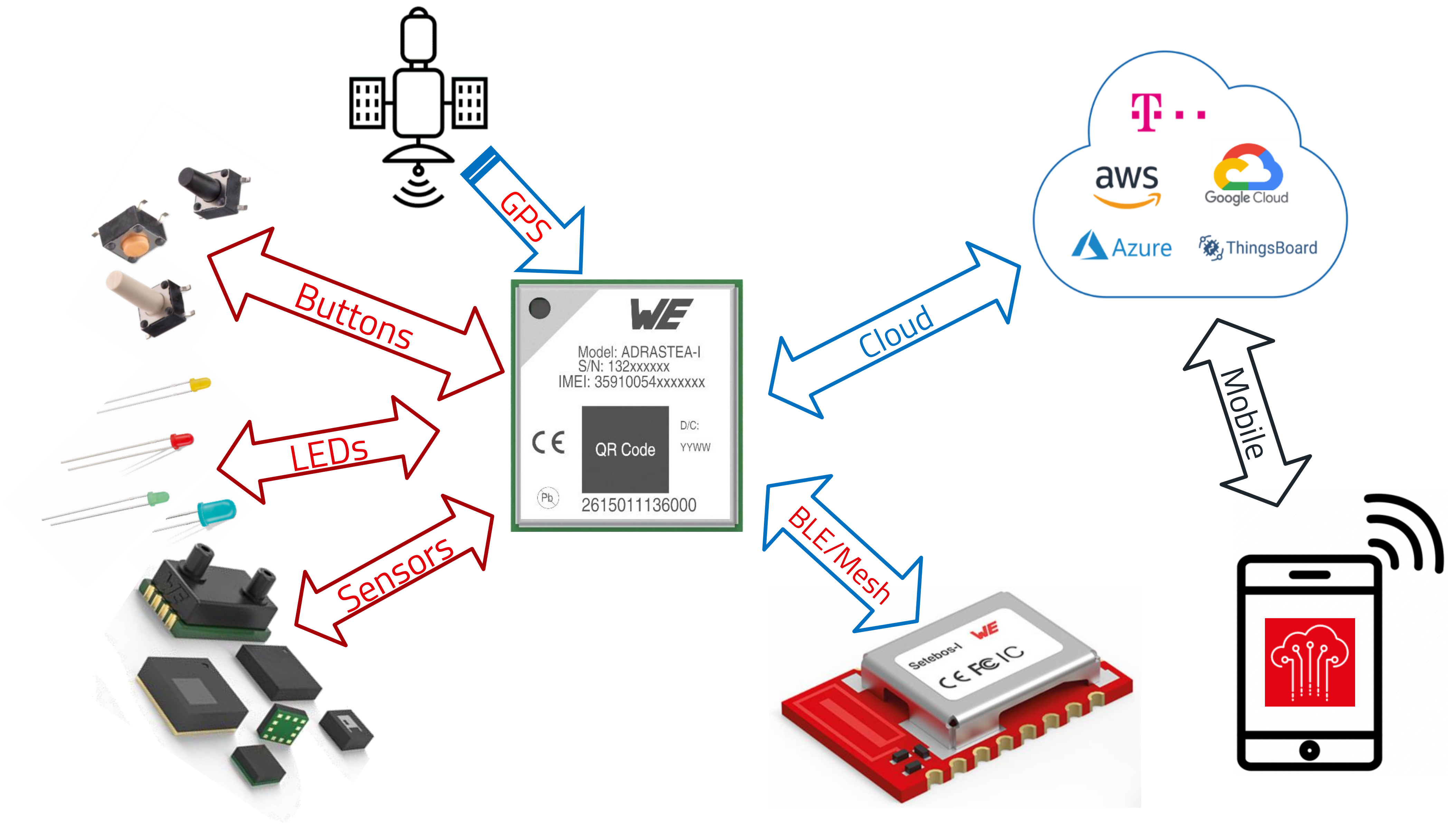
Acceleration



Absolute Pressure



Differential Pressure



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Mh'gōi