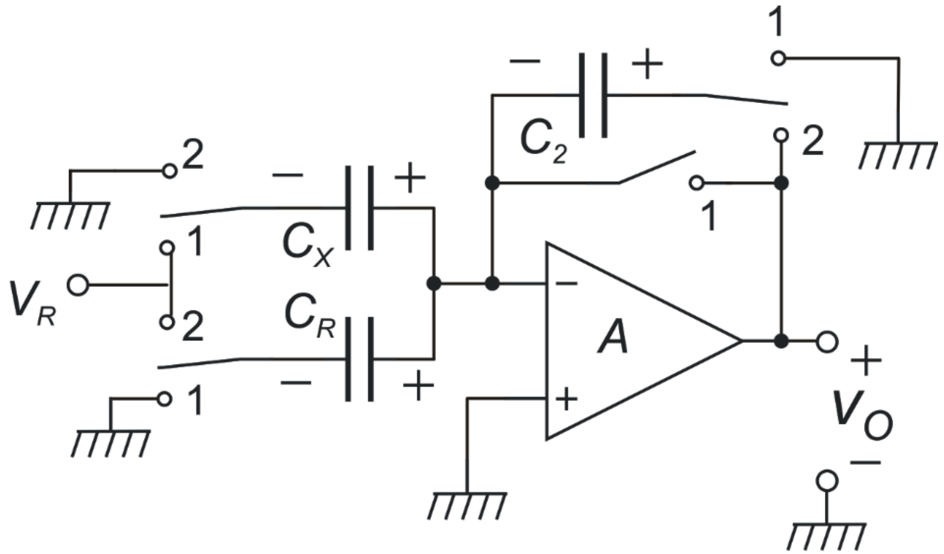
SC charge amplifier design



Sensor:

$80\ \text{fF} \le C_X \le 180\ \text{fF}$

$C_R = 80\ \text{fF}$

$\Delta C_{FS} = 100\ \text{fF}$

Design choices:

$V_R = V_{dd} = 3.3\ \text{V}$ (ratiometric)

$C_2 = \Delta C_{FS} = 100\ \text{fF}$

$$V_{out}^{(2)} = \frac{\Delta C}{C_2} V_R$$

$$0 \le V_{out}^{(2)} \le V_{dd}$$

Ratiometric systems

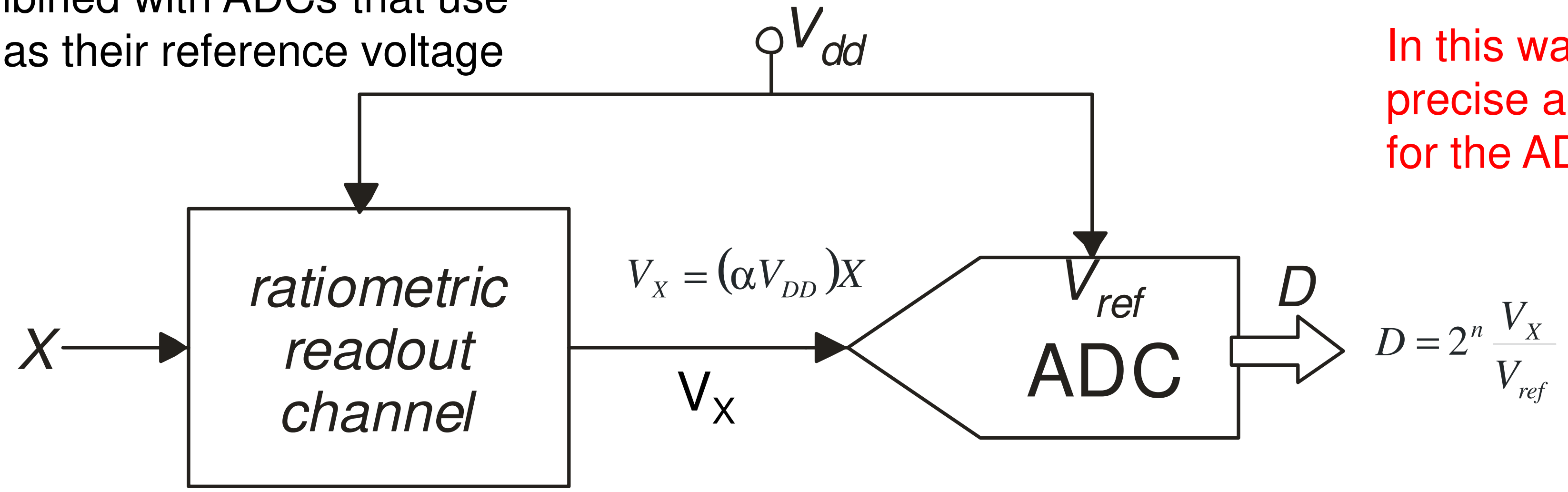
In a ratiometric system, the sensitivity is proportional to the supply voltage V_{dd}.

$$V_X = \underbrace{(\alpha V_{dd})}_{k_X} X$$

$$D = 2^n \frac{V_X}{V_{REF}} = 2^n \frac{(\alpha \cancel{V_{dd}})X}{\cancel{V_{dd}}} = 2^n \alpha X$$

Ratiometric AFEs are often combined with ADCs that use V_{dd} as their reference voltage

In this way the need of a precise and stable V_{REF} for the ADC is removed



Dynamic range (only *kT/C* contribution is analyzed)

$$DR = \frac{V_R}{\underbrace{4\sqrt{kT/\Delta C_{FS}}}_{4125}}\underbrace{\sqrt{\frac{\Delta C_{FS}}{(C_2 + C_X + C_R)}}}_{0.527}$$

= 2174 (66.7 dB , 11.1 bit)

worst case: C_X=180 fF

$$4\sqrt{\frac{kT}{\Delta C_{FS}}} \cong 4\sqrt{\frac{4\times 10^{-21}\ \text{J}}{100\times 10^{-15}\ \text{F}}} = 0.8\ \text{mV}$$

Capacitance resolution

$$\Delta C_n = \frac{\Delta C_{FS}}{DR} = \frac{100\ \mathrm{fF}}{2174} = 0.045\ \mathrm{fF} = 45\ \mathrm{aF}$$

Example: a pressure sensor with linear response, such that:

$$\begin{cases} \Delta C = 0 \Rightarrow p = 0\ \mathrm{Pa}\ (0\ \mathrm{mBar}) \\ \Delta C = 100\ \ fF \Rightarrow p = 200\ \mathrm{kPa}\ (2\ \mathrm{Bar}) \end{cases}$$

$$\mathrm{pressure\,resolution} = \delta p = \frac{\Delta p_{FS}}{DR} = \frac{200\,\mathrm{kPa}}{2174} \cong 90\ \mathrm{Pa}\ (0.9\ \mathrm{mBar})$$

If we have a sensor with all capacitances scaled up by a factor of 10:

Sensor: $0.8\text{ pF} \le C_X \le 1.8\text{ pF}$
$C_R=0.8\text{ pF}$
$\Delta C_{FS}=1\text{ pF}$

$$DR = \underbrace{\frac{V_R}{4\sqrt{kT/\Delta C_{FS}}}}_{13200}\underbrace{\sqrt{\frac{\Delta C_{FS}}{\left(C_2+C_X+C_R\right)}}}_{\text{same ratio as before } 0.527} = 6956 \quad (76.8\text{ dB})$$

$$4\sqrt{\frac{kT}{\Delta C_{FS}}} \cong 4\sqrt{\frac{4\times10^{-21}\text{ J}}{1\times10^{-12}\text{ F}}} \cong 0.25\text{ mV}$$

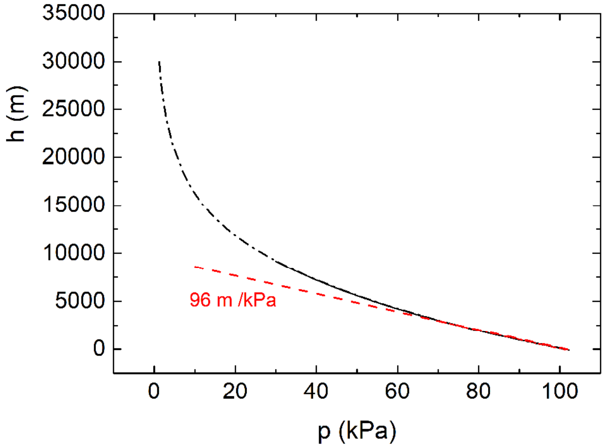
$$\text{capacitance resolution} = \Delta C_n = \frac{\Delta C_{FS}}{DR} = \frac{1\text{ pF}}{6956} = 0.140\text{ fF} = 140\text{ aF}$$

Use of an absolute pressure sensor as an altimeter

$$\frac{dp}{dh} = -\rho(p,T)g$$

USA National Oceanic and Atmospheric Administration

$$h \cong 44307.69\left[1-\left(\frac{p}{102325}\right)^{0.190284}\right]$$



Altitude resolution:

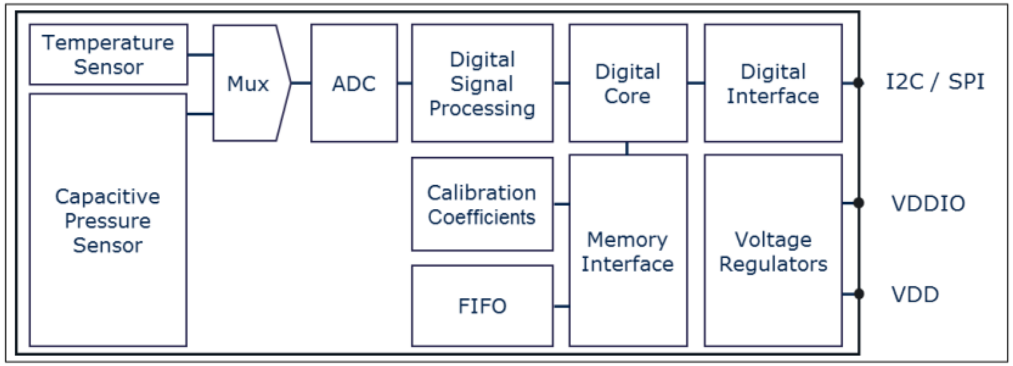
$$h_e = p_e \frac{\partial h}{\partial p} = \quad 8.64 \text{ m}$$

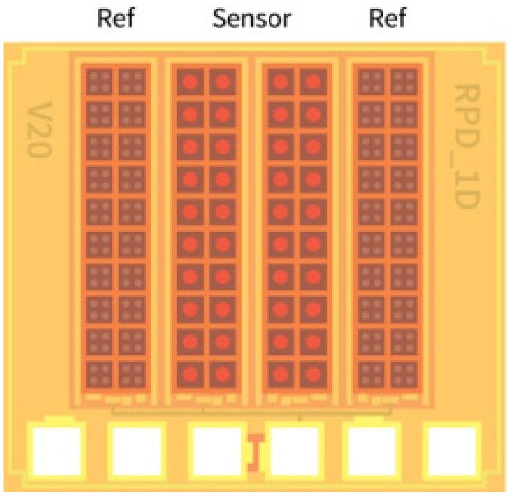
0.090 kPa

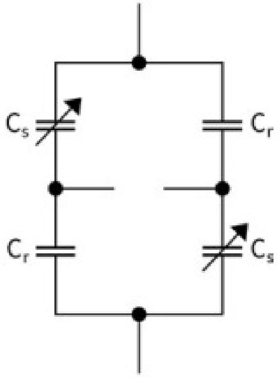
96 m /kPa

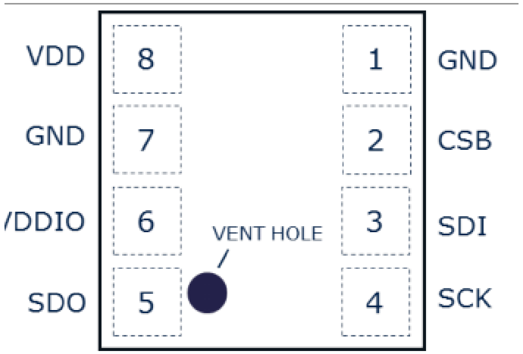
Example of commercial capacitive pressure sensor

DPS310 - Digital Pressure Sensor









Infineon DPS 310 - Specifications

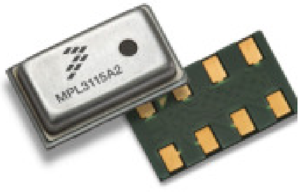
- **Operation range:** Pressure: 300 –1200 hPa. Temperature: -40 – 85 °C.
- **Pressure sensor precision:** ± 0.005 hPa (or ±0.05 m) (high precision mode).
- **Relative accuracy:** ± 0.06 hPa (or ±0.5 m)
- **Absolute accuracy:** ± 1 hPa (or ±8 m)
- **Temperature accuracy:** ± 0.5°C.
- **Pressure temperature sensitivity:** 0.5Pa/K
- **Measurement time: Typical:** 27.6 ms for standard mode (16x). Minimum: 3.6 ms for low precision mode.
- **Average current consumption:** 1.7 µA for Pressure Measurement, 1.5uA for Temperature measurement @1Hz sampling rate, Standby: 0.5 µA.
- **Supply voltage:** VDDIO: 1.2 – 3.6 V, VDD: 1.7 – 3.6 V.

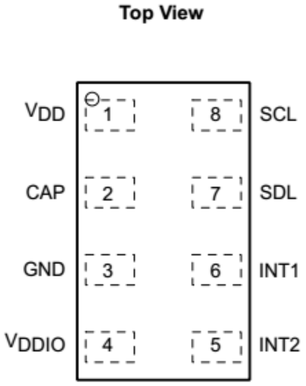
Typical Applications

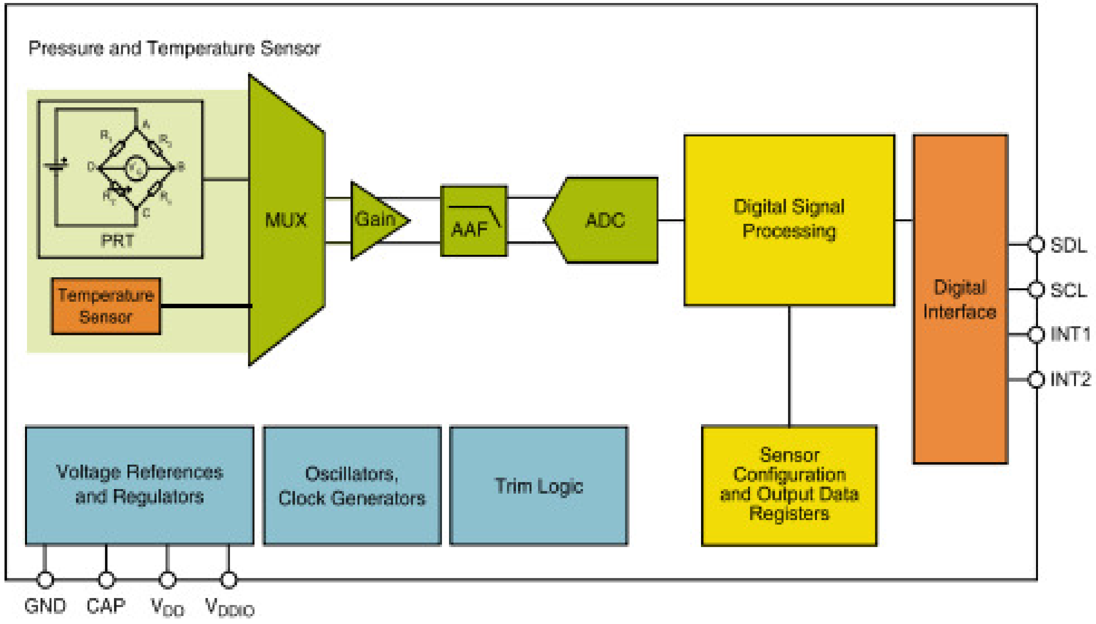
- **Indoor Navigation** (floor detection e.g. in shopping malls and parking garages)
- **Health and Sports** (accurate elevation gain and vertical speed)
- **Outdoor Navigation** (GPS start-up time and accuracy improvement, dead-reckoning e.g. in tunnels)
- **Weather Station**('Micro-weather' and local forecasts)
- **HDD drivers,** (leak rate detection in hard disk drives)
- **Drones** (flight stability and height control)

Example of piezoresistive pressure sensor

Freescale (now NXP) **MPL3115A2** sensor





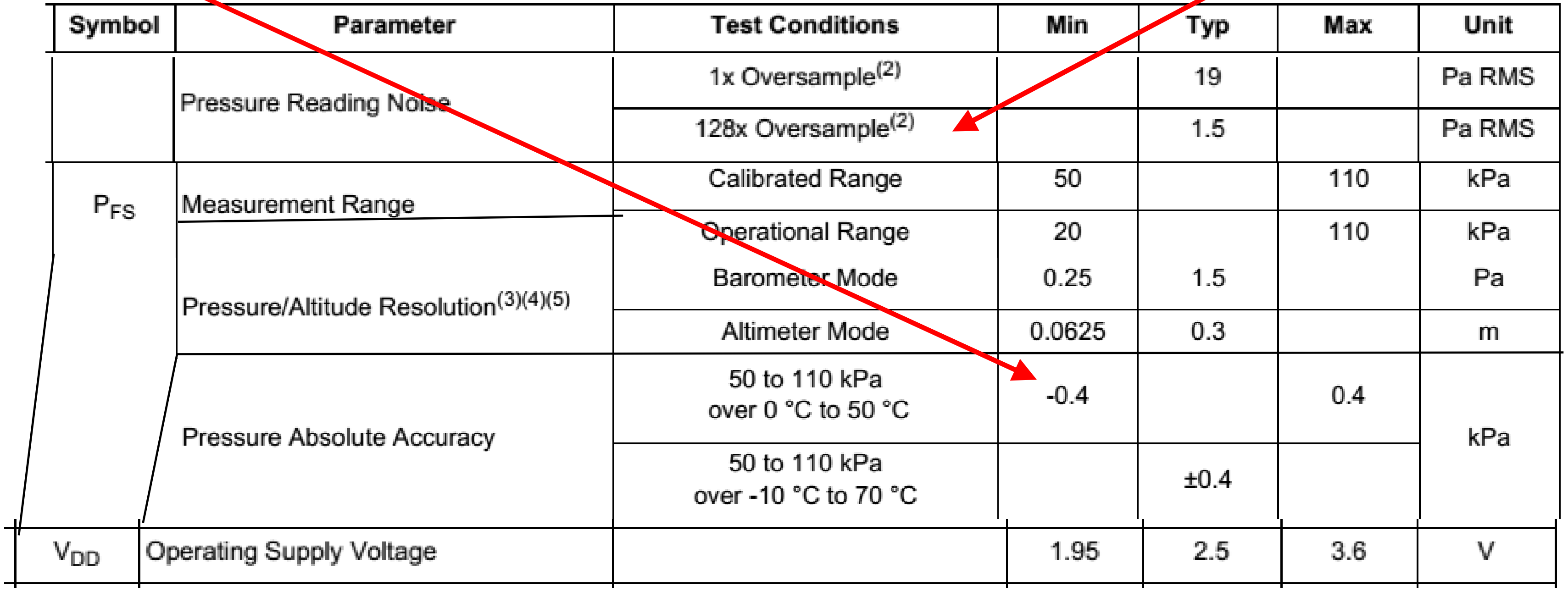


I^2C Digital Interface

MPL3115A2 Specifications

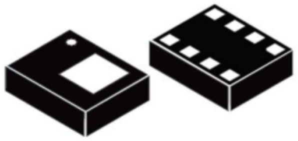
128 samples are averaged
to reduce noise

Accuracy is much worse than resolution, since it dependes also on the offset and other quasi-static errors



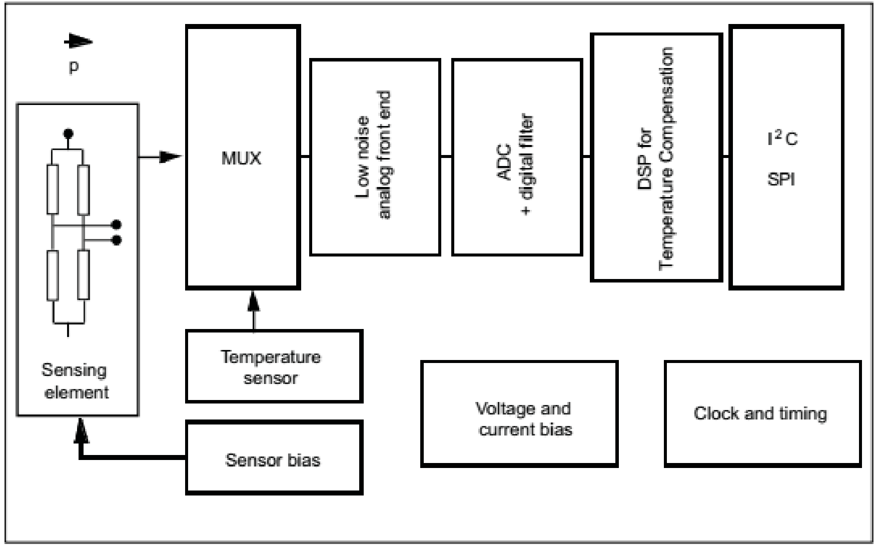
Symbol	Parameter	Test Conditions	Min	Typ	Max	Unit
	Pressure Reading Noise	1x Oversample(2)		19		Pa RMS
		128x Oversample(2)		1.5		Pa RMS
P_{FS}	Measurement Range	Calibrated Range	50		110	kPa
		Operational Range	20		110	kPa
	Pressure/Altitude Resolution(3)(4)(5)	Barometer Mode	0.25	1.5		Pa
		Altimeter Mode	0.0625	0.3		m
	Pressure Absolute Accuracy	50 to 110 kPa over 0 °C to 50 °C	-0.4		0.4	kPa
		50 to 110 kPa over -10 °C to 70 °C		±0.4		
V_{DD}	Operating Supply Voltage		1.95	2.5	3.6	V

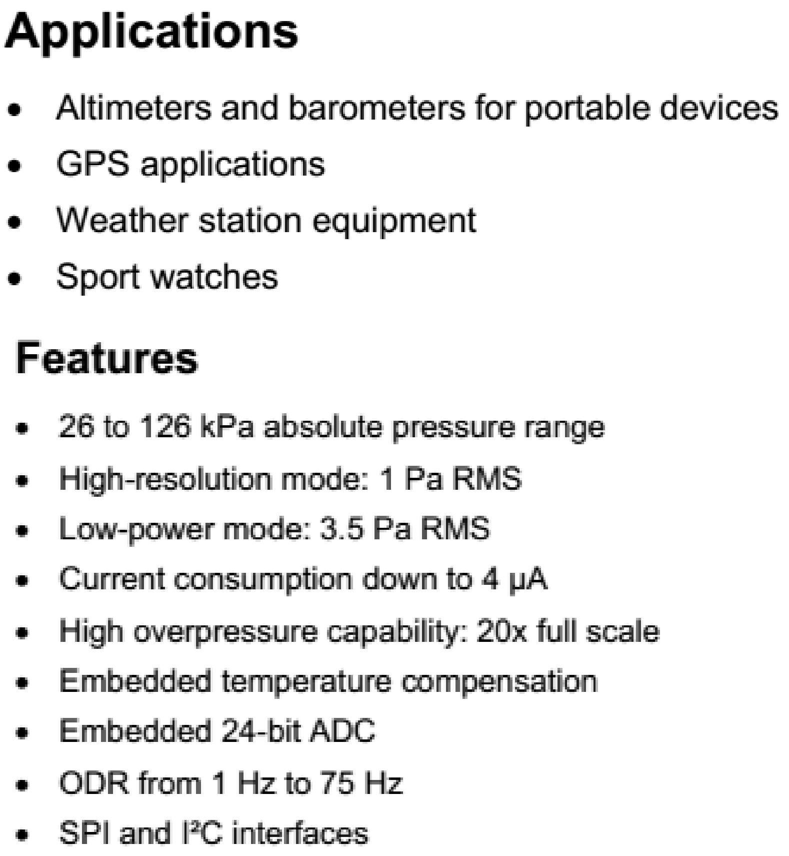
Example of Piezoresistive sensor: STMicroelectronics **LPS225HB**



HLGA 8L
2.0 x 2.5 x 0.8 (max) mm

Figure 1. Block diagram





Applications

- Altimeters and barometers for portable devices
- GPS applications
- Weather station equipment
- Sport watches

Features

- 26 to 126 kPa absolute pressure range
- High-resolution mode: 1 Pa RMS
- Low-power mode: 3.5 Pa RMS
- Current consumption down to 4 μA
- High overpressure capability: 20x full scale
- Embedded temperature compensation
- Embedded 24-bit ADC
- ODR from 1 Hz to 75 Hz
- SPI and I^2C interfaces