Designing with pressure sensors
Solutions and technology from TE Connectivity

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‘Designing with pressure sensors’ webinar

Thank you for joining this webinar presented by Luke Smith, Senior Product Manager, Avnet Abacus and Nicholas Argyle, applications Engineer at TE Connectivity.

- Short introduction to Avnet Abacus and TE Connectivity
- 40 minute technical presentation
- 10 minute Q&A session

The Avnet Abacus and TE Connectivity partnership

Avnet Abacus is part of Avnet, a leading global distributor of electronic components.

We specialise in interconnect, sensors, wireless, passive, power supplies and battery products.

Our extensive team of technical specialists offers design and solution support to engineers across Europe.

TE Connectivity (TE) is a global technology leader, providing connectivity and sensor solutions

With the acquisition of Measurement Specialties (MEAS), a global designer and manufacturer of sensors and sensor-based systems, TE is one of the largest sensor companies in the world

Together we bring you a portfolio of high-performing Sensor solutions and associated technologies that enable you to transform concepts into smart connected designs across a wide range of applications

TE connectivity

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Designing with pressure sensors

The key themes we will cover in this webinar are:

- Pressure sensor base technologies – an in depth look at the products, how they are constructed, their parameters and example products
- Choosing the right pressure sensor for your application – Key points for consideration
- Configuring a sensor from the datasheet
- Customisation options, when an off the shelf solution will not suffice

Agenda

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TE Sensor Solutions (TESS) overview

PRODUCT PORTFOLIO KEY FACTS

- Portfolio includes technologies capable of measuring most physical characteristics
- Sensors used in virtually all end markets
- Specialises in custom sensing solutions
- Focus on highly engineered, application-specific solutions

KEY FACTS ABOUT SENSOR MARKET

- Global sensor market expected to grow from $80B in 2014 to $116B in 2019
- Sensors and connectors have common end market segments and customer base
- Sensor market is highly fragmented with few large incumbents
- Global trends of green, safe, connected and reliable systems are driving sensor and connector content growth

With a position in both sensors and connectors, TE will be able to lead in providing system-level solutions

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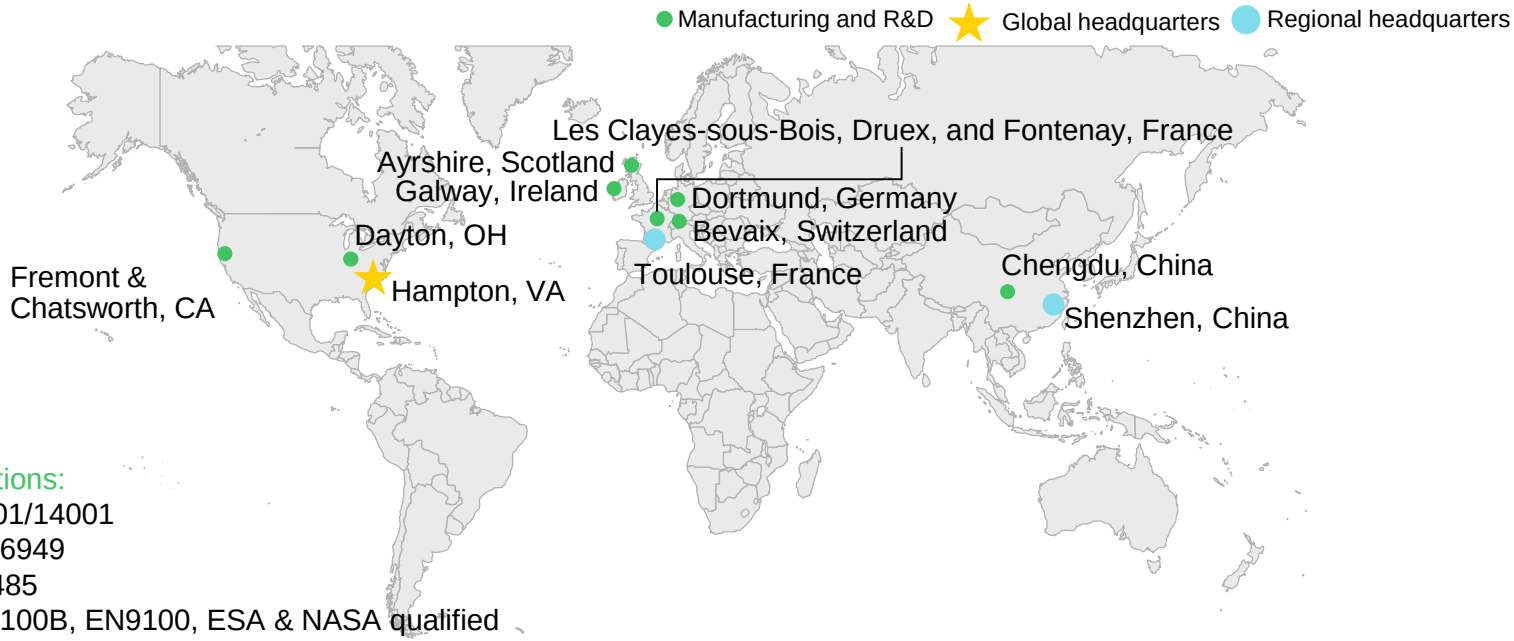
TE Sensor Solutions worldwide resources



Quality Certifications:
General: ISO9001/14001
Auto/Truck: TS16949
Medical: ISO13485
Aerospace: AS9100B, EN9100, ESA & NASA qualified

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TE Sensor Solutions – Industries & Technologies

Industries Served

- Aerospace and defence
- Appliances
- Automation and control
- Consumer
- Industrial
- Intelligent buildings
- Medical
- Oli and gas
- Test and measurement

Sensor types

- Digital component
- Flow, force, humidity
- Liquid level
- Photo optic
- Piezo film
- Position, pressure, temperature
- Rate and inertial
- Scanners and systems
- Torque, ultrasonic, vibration
- Water level

TE acquired brands

MEASUREMENT SPECIALTIES

IC SENSORS

ELEKON

ENCODER DEVICES

HUMIREL

AST

CELESCO

INTERSEMA

ENTRAN

MACRO SENSORS

SENTELLIGENCE

WEMA

PRESSURE SYSTEMS

PIEZOFILM SENSORS

SCHAEVITZ SENSORS

GENTECH

FGP SENSORS

VISYX

HL PLANER TECHNIK

YSI TEMPERATURE

RTD COMPANY

ATEXIS

API TECHNOLOGIES CORP

BETATHERM SENSORS

SENSOTHERM

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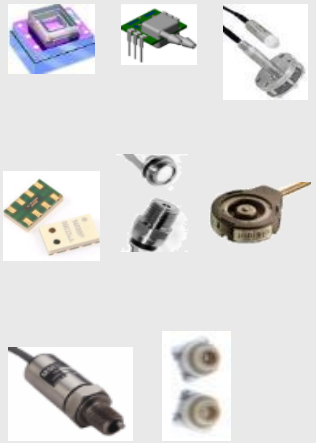
TE sensor portfolio overview

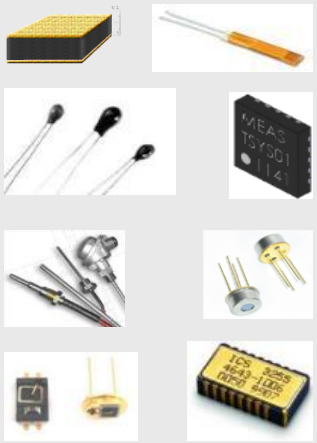
PRESSURE SENSORS & LOAD CELLS

- MEMS Die and Oil filled
- MEMS Si Strain Gauge
- Altimeters & Barometers
- BFSG Technology



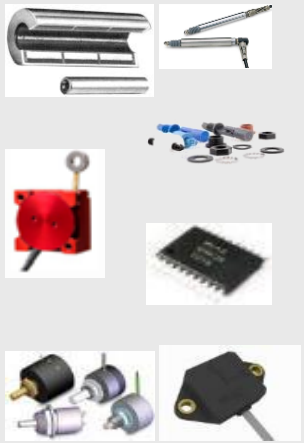
TEMPERATURE, HUMIDITY, & HEATERS

- NTC Thermistor
- Platinum & Nickel RTD
- Thermocouple
- Non-contact IR
- PTC Heaters



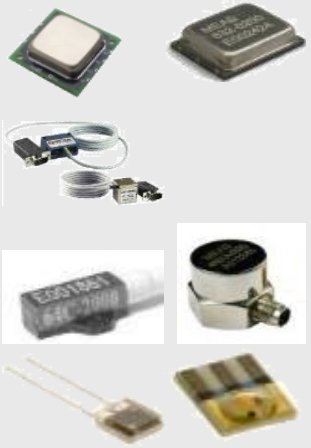
POSITION, ROTARY, & TILT

- LVDT/RVDT
- M-R Rotary
- Inclinometers
- AMR Magnetics
- Precision Resistive



VIBRATION & OPTICAL

- Accelerometer
- Vibration
- Rate Gyros
- Tilt
- Visible & IR



PIEZOELECTRIC SENSORS

- Piezo Polymer Film
- Liquid Level Sensors
- Air Bubble Detectors
- Contact Microphones

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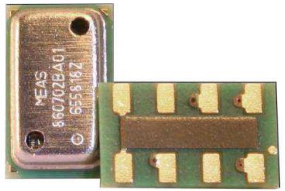
Pressure sensing

TE pressure sensor overview



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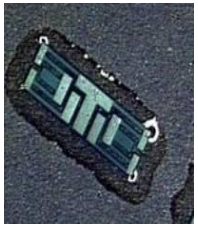
Pressure sensing
TE base technologies

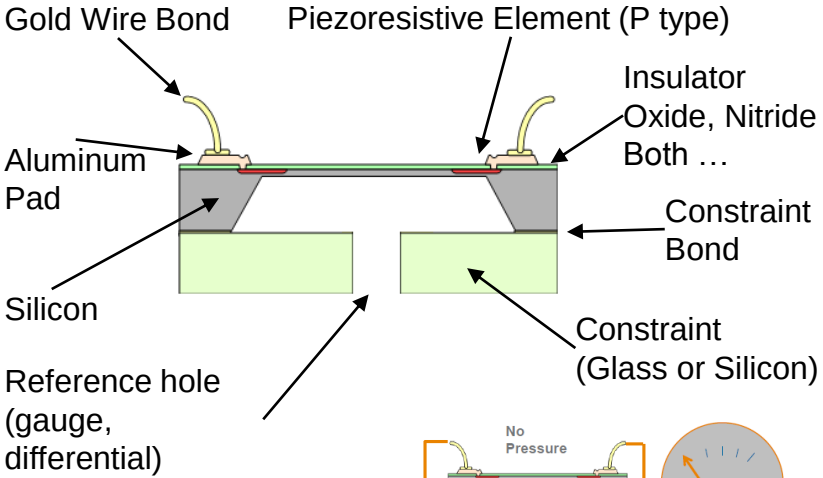
Base technologies

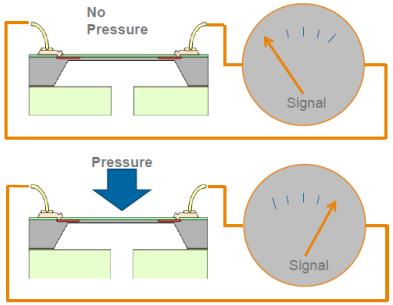
1. MEMS Piezo-Resistive
   - “Ultrastable™”
   - “Harsh Media” (media isolated)
2. MEMS Silicon strain gauge
   - “Microfused™ technology
3. Bonded foil strain gauge (BFSG)
   - Robust applications

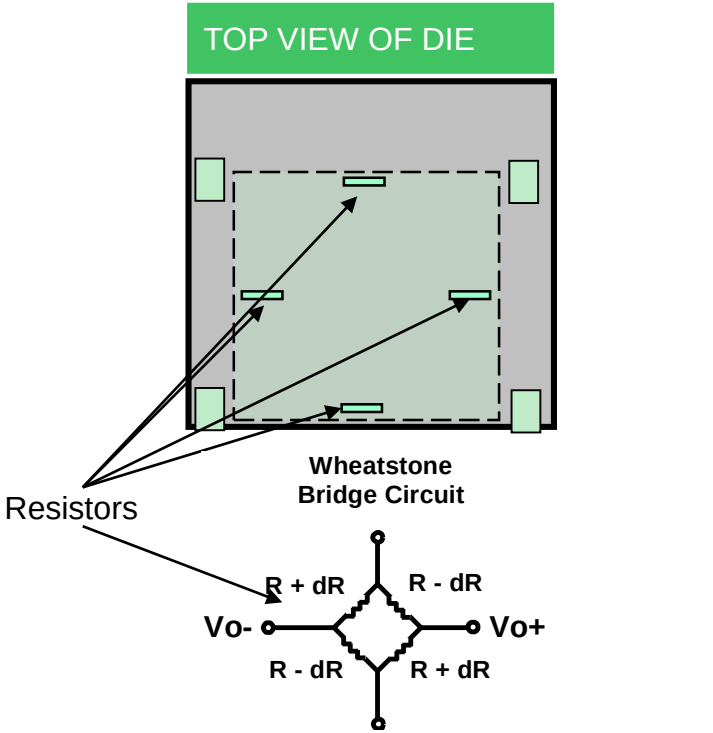


MEMS (Micro-Electro-Mechanical Systems) Piezo-Resistive pressure sensing

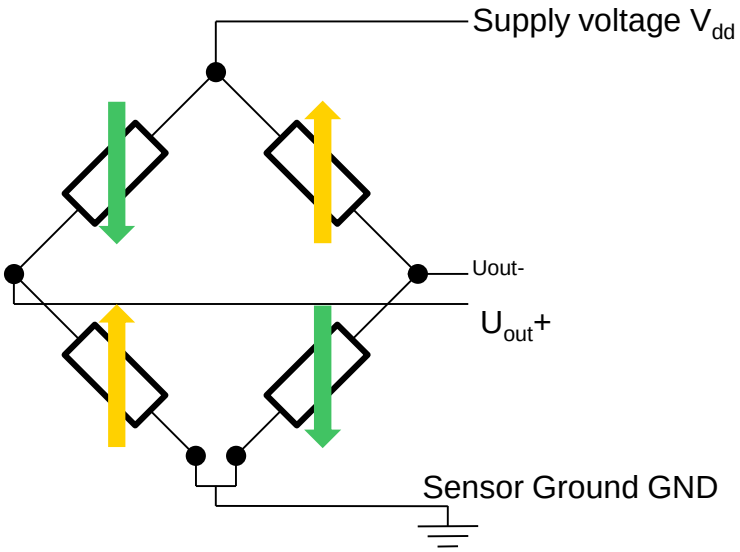
Piezo-resistive sensor cross-section







Principle of measurement



mV pressure die have “ratio-metric” outputs

Resistance measurement

– The resistors are arranged in a Wheatstone bridge

Bending of membrane

– Pressure difference between the top side and the vacuum reference (under side for differential sensors) will lead to displacement of membrane of typically 1.5 µm

Change of resistance

– The resistance of the Piezo resisters will change

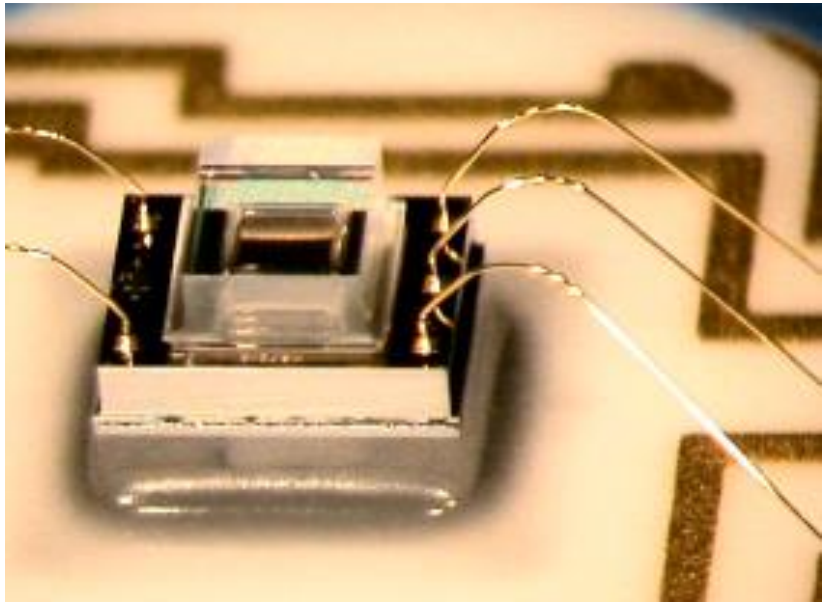
– Typically 150mV full scale signal at 5V (1 bar / 14.5 PSI sensor)

Temperature Dependency

– The change in resistance is depending on the temperature → temperature calibration is needed

– Temperature information can be taken from sensor directly

Sensors measure extremely small stress!

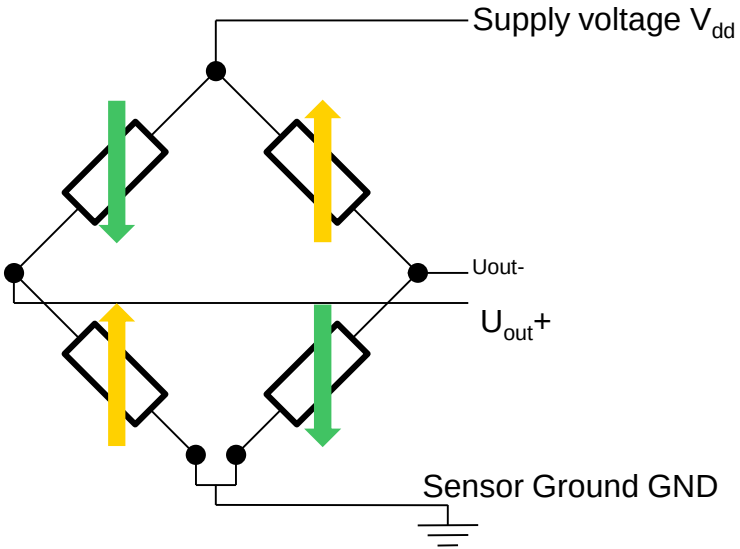


0.1 mbar is equivalent to 0.1 nanometer of membrane deflection !

Pressure at sea level = 1013.25 mbar = 101.325 KPa

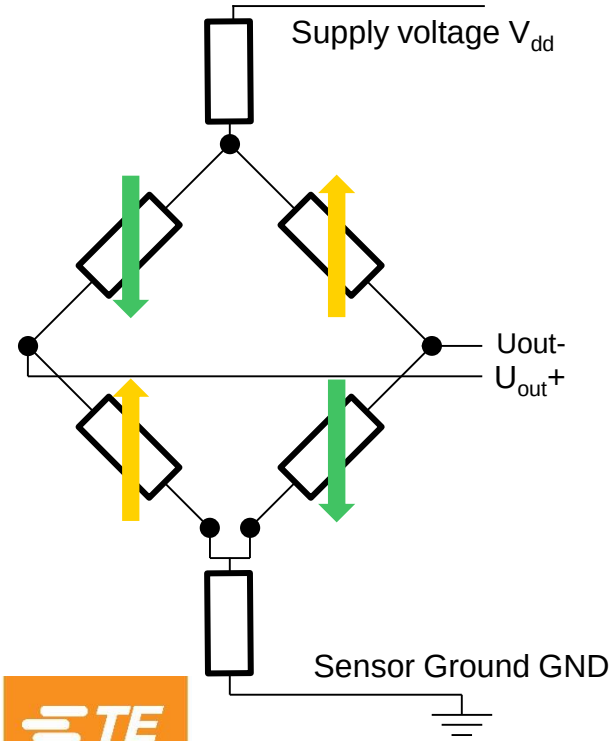
At sea level the atmospheric pressure decreases approx 0.1 mbar per 1 meter of altitude.

Types of sensors – uncompensated (mV)

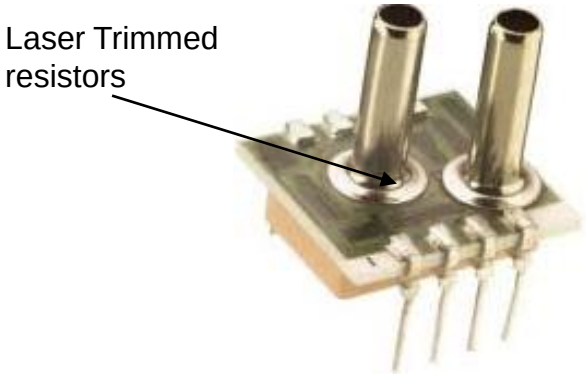


- Do NOT have temperature compensation and do not have a calibrated zero offset
- Ratio-metric output
- Wide zero offset tolerance (i.e -5 to 20mV) @ 5V
- Wide Span tolerance (i.e 50 to 200mV) @ 5V
- Low cost option
- Requires more external circuitry and set up

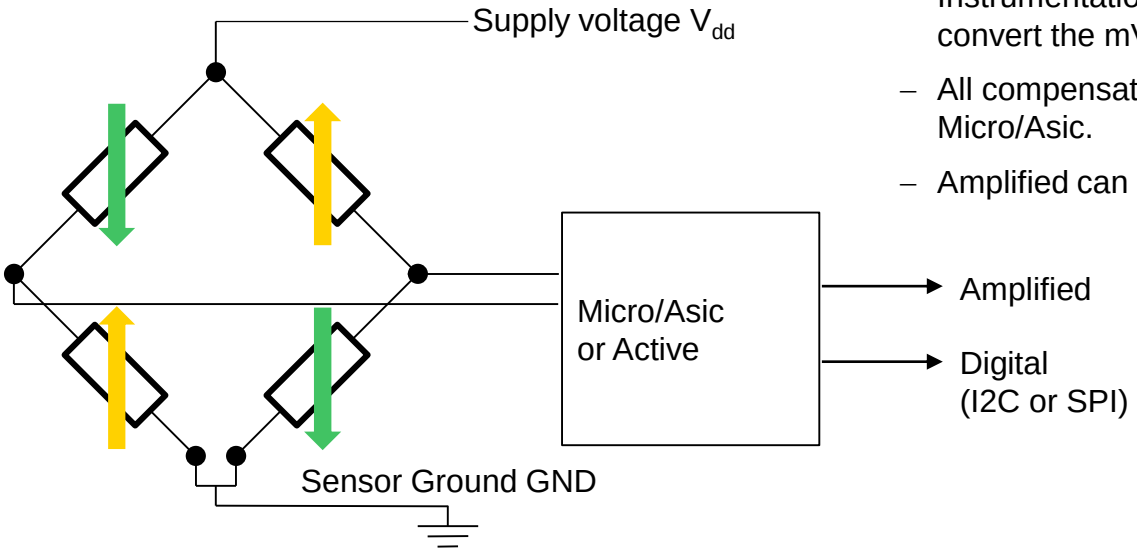
Types of sensors – compensated and calibrated (mV)



- External compensation resistors to stabilise the output characteristics with variations in temperature
- Resistors mounted on ceramic hybrid (thermally stable) and laser trimmed
- Zero offset calibrated again via laser trimmed resistors. Small offset (i.e 0mV +/-2mV)
- Span adjusted for a tight tolerance. (i.e 100mV +/-2mV)



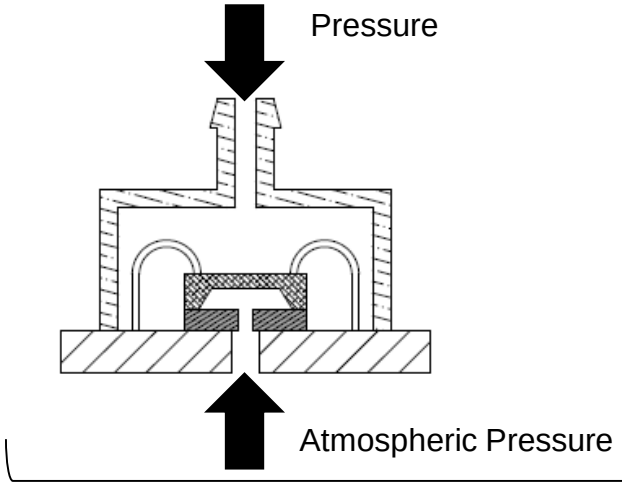
Types of sensors – amplified and digital



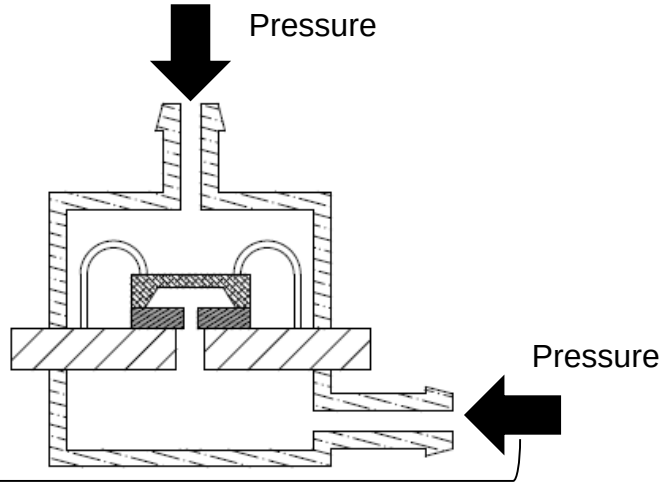
- Instrumentation Micro Controller / Asic is used to convert the mV signal into an Digital (I2C / SPI) signal.
- All compensation/Calibration is programmed in the Micro/Asic.
- Amplified can be Active output or D-A conversion.

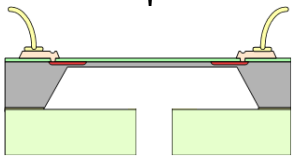
Pressure sensing fundamentals

GAUGE



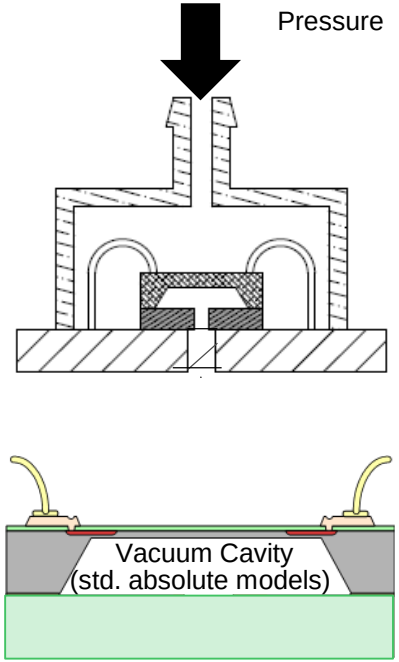
DIFFERENTIAL



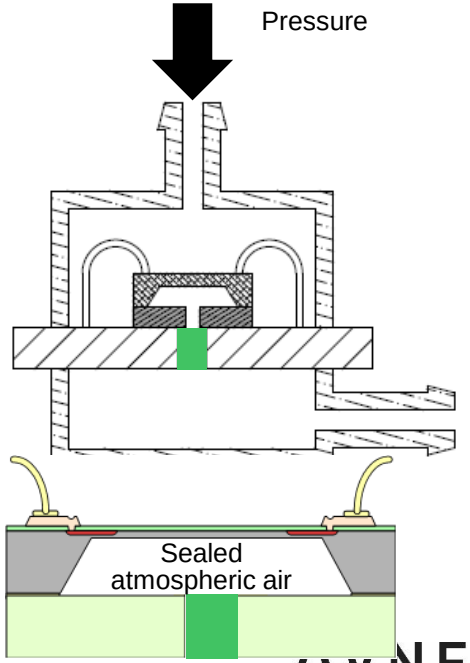


Pressure sensing fundamentals

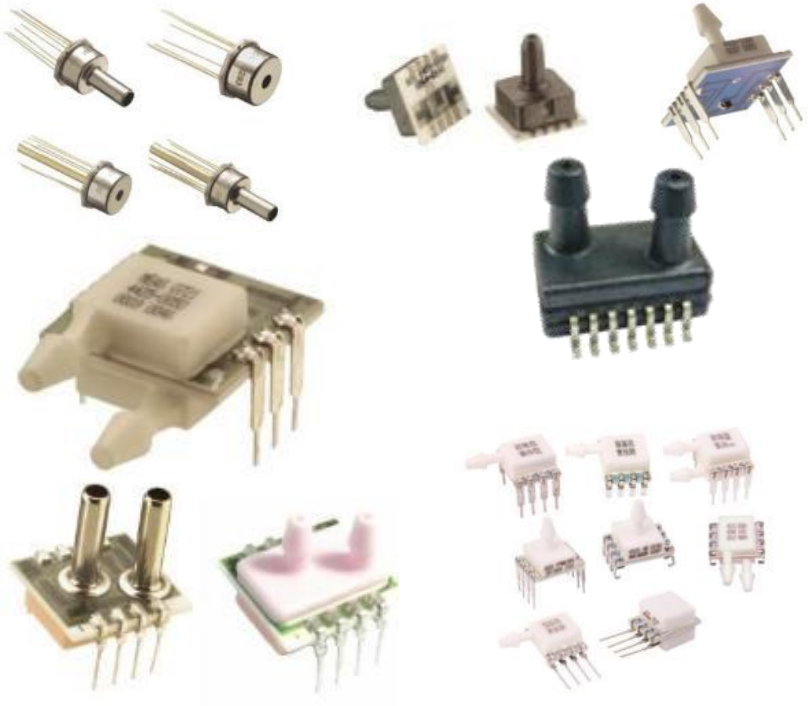
ABSOLUTE



SEALED GAGE



Board-mount pressure sensors



Pressure range
- 2 InH20 to 300 psi
- Gauge, Absolute, Differential, Compound Pressures

Packages
- Ceramic and plastic SMD
- Ceramic Leaded
- TO Cans

Outputs
- mV Output.
- mV Output, Temperature Compensated.
- Amplified. 0.5 to 4.5V.
- Digital Output.

Board-mount pressure sensors

mV Uncompensated & Uncalibrated Sensors:

- MS1451

mV Compensated & Calibrated Sensors:

- 1210, 1220, 1230 & 1240
- 13, 23, 33, 43, 17, 27, 37 & 47 (TO8 package)
- MS4425 & 4426
- MS1471
- MS52xx & MS54xx.

Amplified Sensors:

- MS4515 & MS4525
- MS5525ASO (moulded package – High quantity).

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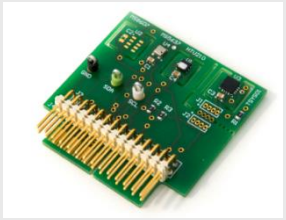
Board-mount pressure sensors

Digital Sensors (not including calibrated altimeters/barometers):

- MS4515DO & MS4525DO.
- MS5525DSO (moulded package – high quantity)
- MS5803 (abs and gel fill).
- MS5837 (abs).

Board-mount pressure sensors applications

PCB MOUNT	ALTIMETER	PNEUMATIC CONTROL
		
MEDICAL	**HVAC AIRFLOW**	**AIRSPEED**
		

Altimeters and barometers

Pressure range
- 10 mbar to 2000 mbar
- Absolute

Packages
- Ceramic SMD
- DFN
- QFN

Outputs
- mV Output, Uncompensated
- Digital Output, Calibrated and Temperature Compensated

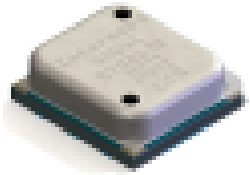
Resolution
- 14 or 24 bits

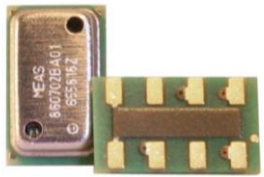
Temperature Sensor
- Digital output
- -40 to +85°C

Altimeters and barometers

- MS5607
- MS5611
- MS5637 (inc temp in device)
- MS5805 (Gel fill)
- MS8607 (inc humidity and temp in device)

NOTE: you can use ANY 1bar absolute sensor and calibrate into a altimeter/barometer





Altimeters and barometer applications

GPS NAVIGATION

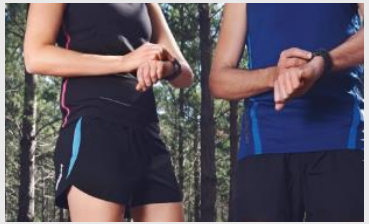
HOBBY DRONE

MOBILE PHONE

WEATHER STATION

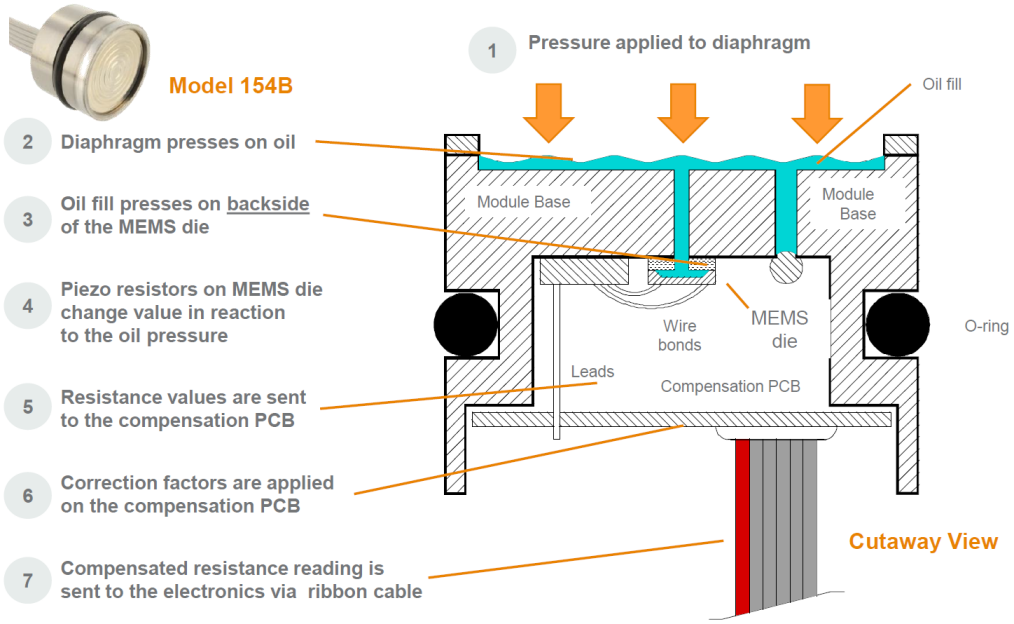
WEARABLES

SPORT WATCH



Ultra stable pressure capsules

MEMS Die – Media isolated stainless pressure cell
70 mbar (1 psi) to 666 Bar (10K psi)



Ultra stable pressure capsules

Model 82
- 19mm dia
- Low Pressure (down to 1psi)

Model 85
- 13mm dia
- Medium Pressure – High Accuracy

Model 86
- O-ring Mount
- Millivolt, Amplified or Digital outputs

Model 89
- 8mm dia
- High Pressure (up to 5000psi)

Model 154N
- 19mm dia
- O-ring Mount

Model 86D
- O-ring Mount or w/fittings
- Differential Pressure

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Medical applications

- Ventilators
- Oxygen concentrator
- Vaporisers
- Gas delivery (oxygen)
- Gas blenders
- CPAP
- Digital flow meters
- Nitric oxide therapy
- Drug delivery
- Inhalers (intelligent)
- Pressure therapy mattresses
- Wound therapy / drainage
- Blood pressure
- Altitude correction for gas flow

Industrial and HVAC applications

- Ink printing
- Data loggers
  - Water utility
  - Gas utility
- Gas sampling (inc portable)
- Air/Gas pressure control
- Filter / flow monitoring
- Pressure controllers
- Compressors
- Steel mills (roller pressure)
- Cryo systems
- Lab water level monitoring
- Diesel tank level monitoring
- Burner control
- Gas pressure leakage

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Ultra stable pressure transmitters

US300

U7100

U5200

U5300

D5100

Model US300
- Low cost
- Survive hostile media

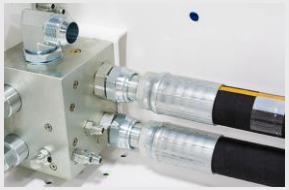
Model U7100
- Small size
- Low pressure ranges available

Model U5200
- Excellent performance
- Large number of std configurations

Model U5300
- Best performance
- Rugged housing

Model D5100
- True differential measurement
- High level output

Ultra-stable pressure tx'er and capsule applications

PNEUMATIC/HYDRA-ULIC CONTROL	MEDICAL	AUTOMOTIVE	SENSOR BUILDING BLOCK	MANIFOLD
				

Submersible pressure / liquid level transducer

Packaging

- Designed for hostile environments
- 316 stainless steel or titanium
- Waterproof construction
- Moisture barrier in vent tube

Performance

- Up to ±0.25% accuracy
- Vented gauge or sealed gauge
- 5 to 50 psi ranges
- Available with nose cone
- Available with anti-fouling front end

Applications

- Liquid level in storage tanks
- Water level in reservoirs and lakes
- Sewage treatment
- Salt water and brine depth

Submersible pressure / liquid level transducer applications

IRRIGATION WATER LEVEL

SEWAGE TREATMENT

STORAGE TANK LEVEL

WATER QUALITY MONITORING

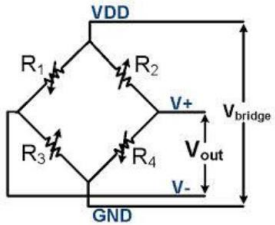
Microfused
Silicon strain gauge

Microfused™ silicon strain gauge pressure sensor

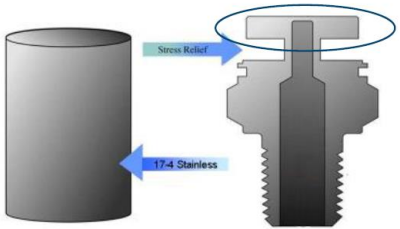
3.5 BAR (50 PSI) TO 1K BAR (15K PSI)

Model MSP-300

Wheatstone Bridge

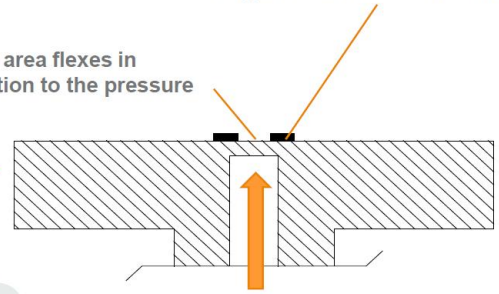


Front end is machined from a single piece of stainless steel very high reliability



3 Piezo resistive strain gauges change value in reaction to the flex

2 Thin area flexes in reaction to the pressure



1 Pressure applied to sensor port

Microfused pressure sensors

MSP-100

MSP-300

MSP-340

M5100

M7100

Pressure range

- 15 psi to 30,000 psi
- Gauge, absolute

Packages

- Threaded port (male & female)
- Hermetic front end
- Compensation and gain in package

Outputs

- mV Output, uncompensated
- 0.5V to 4.5V compensated
- 1.0V to 5.0V compensated
- 4 to 20 mA compensated
- Cable or connector interface

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Microfused pressure sensor applications

REFRIGERATION

MEDICAL GAS

HYDRAULIC SYSTEMS

PAINT SPRAYER

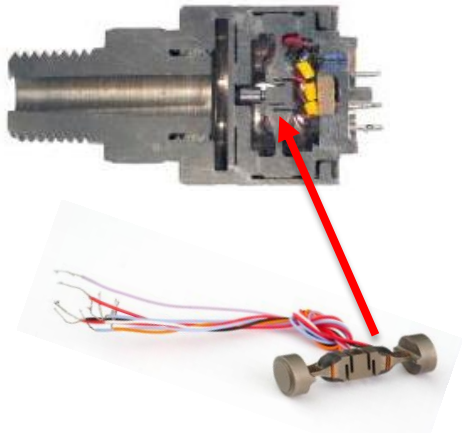
PNEUMATIC CONTROLS

INDUSTRIAL PROCESS

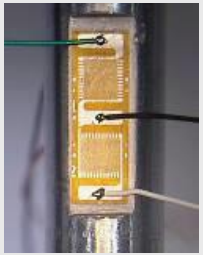
COMPRESSOR

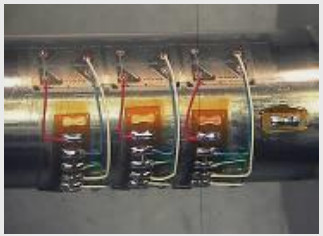
Bonded foil strain gauge (BFSG)

Bonded foil strain gauge (BFSG)



RANGES FROM 0 TO 5BAR, UP TO 7KBAR.
VERY HIGH OVERPRESSURE.





- The principle of the transducer is a force-summing diaphragm coupled via a force rod (pushrod) to a strain-gauged double cantilever beam with integral isolation, forming a four-arm Wheatstone bridge in a very symmetrical manner.
- This sensor assembly transduces the force applied to the sensor diaphragm into a millivolt output.
- This construction has very high over pressure capabilities!

BFSG PRODUCTS

ANALOGUE SINGLE END MEASUREMENT:

- P700 (amplified, 4-20mA)
- P900 (amplified, 4-20mA)
- P981 (amplified, 4-20mA)
- P1200 (amplified, 4-20mA)
- P9000 (amplified, 4-20mA)
- P101 (mV, amplified)
- P105 (mV, amplified)
- P125 (mV, amplified)

Determining what pressure sensor to use

- What is the application?
- What is the media (dry gas / air or liquid)?
  - If liquid – media isolated cells or transmitters (exception – if moist liquid and for short duration, you can look at gel filled board mount sensor
  - If Air/Dry Gas – any sensor
- What is the pressure range?
- Do you want to measure gage, absolute, differential or sealed gage?
- What is the required output (mV, amplified, digital or other)?
- Do you require board mount, media isolated cell or transmitter?
- What is the process connection (cells / transmitters – i.e ¼" BSP thread)?
- What electrical interface on the rear (cable, M10, other etc)?
- What is the required temp range (operating and compensated range)?
- Any IP rating (IP65, IP67 etc)?
- Quantity?

Configuring a sensor from the datasheet

ORDERING INFORMATION

4525DO	-	DS	3	A	I	004	G	P	
Model	**-**	**Package Style**	**Supply Voltage**	**Output Type**	**Interface Type**	**Pressure Range (psi)**	**Pressure Type**	**Pin Style**	**Option Type**
MS4525DO	-	**SS** = Single Sideport **DS** = Dual Sideport **TP** = Top Port **MM** = Manifold Mount	**3** = 3.3 Vdc **5** = 5.0 Vdc	**A** = 10% to 90% **B** = 5% to 95%	**I** = I²C (Addr.0x28H) **J** = I²C (Addr.0x36H) **K** = I²C (Addr.0x46H) **S** = SPI (not available for 'L' pin style) **0** = I²C (Addr.0x48H) : **9** = I²C (Addr.0x51H)	**001** **002** **005** **015** **030** **050** **100** **150**	**A** = Absolute **D** = Differential **G** = Gage **C** = Compound **V** = Vacuum	**P** = Thru Hole **S** = J Lead **L** = In Line	**Blank** = No Option **F** = Gel Coating **L** = Low Power **M** = Gel Coating and Low Power

Example: 4525DO-DS3AI005DPL

Model 4525DO, Dual Sideport, 3.3V, 10-90%, I2C addr 0x28H, 5psi, Differential, Thru hole, Low power.

Value add – customisation

Board mount sensors:

- Special calibrations (i.e -30 to 200mBar) – easier with Asic based sensors
- Different Ports – mould tools required
- Gel coatings for media resistance

Media isolated sensors:

- Special threads. (quick connect etc)
- Potted rear electronics
- Cable length / type
- Connectors

Transmitters:

- Threads
- Cables
- Housing

Q&A and further resources

There will now be a 10-minute Q&A

Further resources – click here to:

- speak to one of our technical specialsits in your local language
- download the Avnet Abacus white paper *Pressure sensors, design considerations and technology options*
- read the TE sensor overview
- view a recording of this webinar (available 48 hours after the webinar)
- share the on-demand version with your colleagues
- Download the full slide deck, along with additional information we didn't have time to include

Thank you!

TE connectivity
AUTHORIZED DISTRIBUTOR

AVNET ABACUS

Appendix

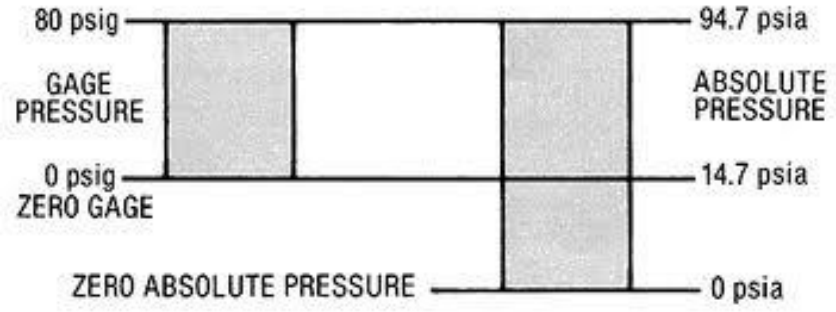
Pressure sensor fundamentals

Pressure conversion units

	kPa	bar	psi	kgf/cm^2	mmH$_2$0	inH$_2$O	ftH$_2$0	mmHg	inHg	torr
kPa	**1**	0,01000	0,14504	0,01020	101,972	4,01463	0,33455	7,50064	0,29530	7,50064
bar	100,000	**1**	14,5038	1,01972	10197,2	401,463	33,4552	750,064	29,5300	750,064
psi	6,89476	0,06895	**1**	0,07031	703,070	27,6799	2,30666	51,7151	2,03602	51,7151
Kgf/cm^2	98,0665	0,98067	14,2233	**1**	10000,0	393,701	32,8084	735,561	28,9590	735,561
mmH20	0,00981	0,00010	0,00142	0,00010	**1**	0,03937	0,00328	0,07356	0,00290	0,07356
inH20	0,24909	0,00249	0,03613	0,00254	25,4000	**1**	0,08333	1,86833	0,07356	1,86833
ftH2O	2,98907	0,02989	0,43353	0,03048	304,800	12,0000	**1**	22,4199	0,88267	22,4199
mmHg	0,13332	0,00133	0,01934	0,00136	13,5951	0,53524	0,04460	**1**	0,03937	1,00000
inHg	3,38639	0,03386	0,49115	0,03453	345,316	13,5951	1,13292	24,4001	**1**	25,4001
torr	0,13332	0,00133	0,01934	0,00136	13,5951	0,53524	0,04460	1,00000	0,03937	**1**

Offset

- Offset is defined as the output of the sensor at it's minimum or reference pressure. NO pressure applied.
- For vented gauge / differential, the reference pressure is atmospheric pressure.
- For Absolute, the reference pressure is vacuum.



(1013mbarA)

(Sea Level)

(Space)

Very Important!! – Usually the first characteristic to check if there are issues.

Span

SPAN IS DEFINED AS THE ALGEBRAIC DIFFERENCE BETWEEN THE OUTPUT AT ZERO PRESSURE AND THE OUTPUT AT FULL SCALE PRESSURE.

Examples:

Output at zero pressure = 1mV

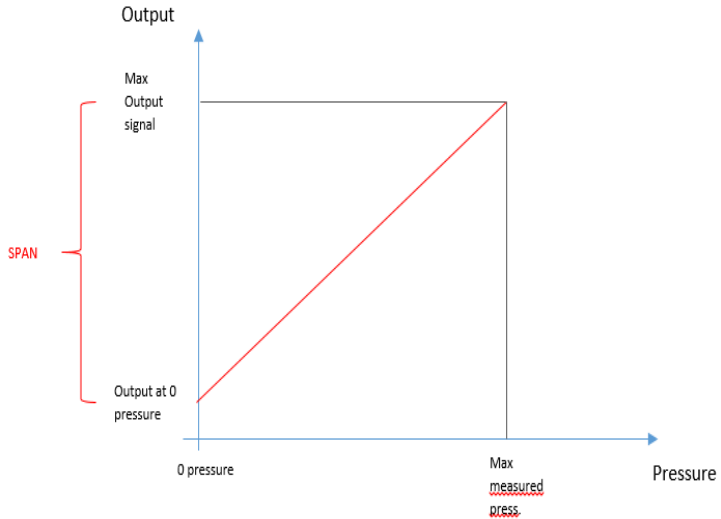
Output at full scale pressure = 101mV

Span = 100mV

Output at zero pressure = 0.5V

Output at full scale pressure = 4.5V

Span = 4V.

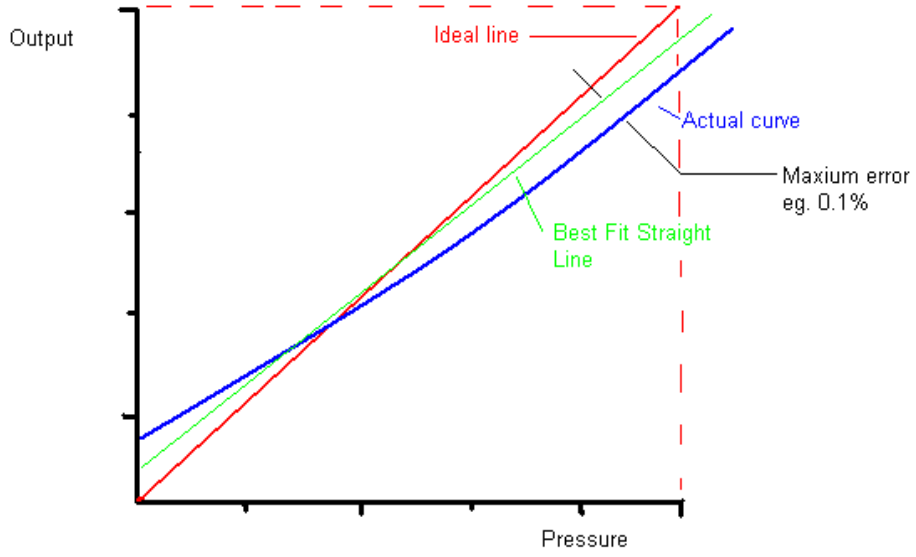


Linearity / static accuracy

- The linearity (often referred to as non-linearity) is a measure of the sensors' ability to provide an output that is directly / linearly proportional to the pressure input.
- It is generally specified as a deviation from a Best Fit Straight Line (BFSL or BSL), expressed as a percentage of full scale.
- You will often see this denoted as CNLH – Combined Non-Linearity and Hysteresis or NLH or NLH&R (where R = Repeatability)
- Hysteresis is defined as an error that occurs when any single signal reading is approached from opposite directions. Hysteresis error is usually expressed as a percent of full-scale output.

Linearity / static accuracy

BEST FIT STRAIGHT LINE



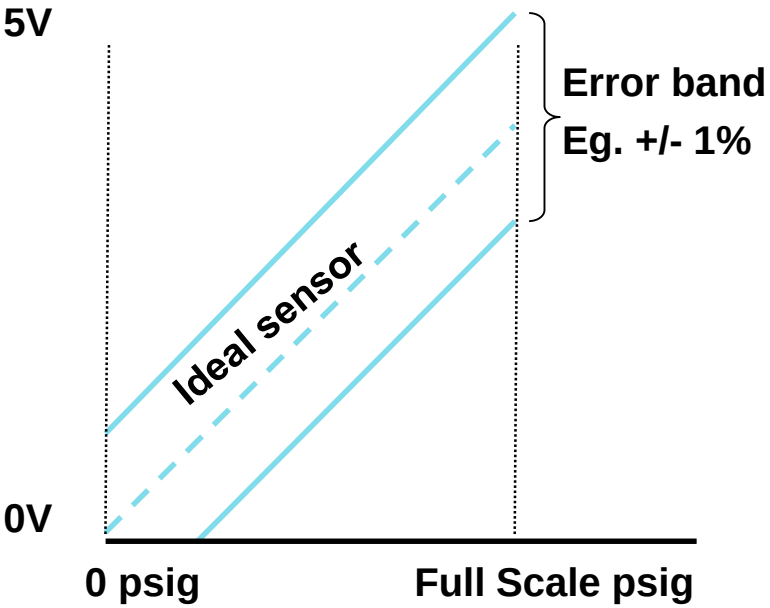
Thermal drift

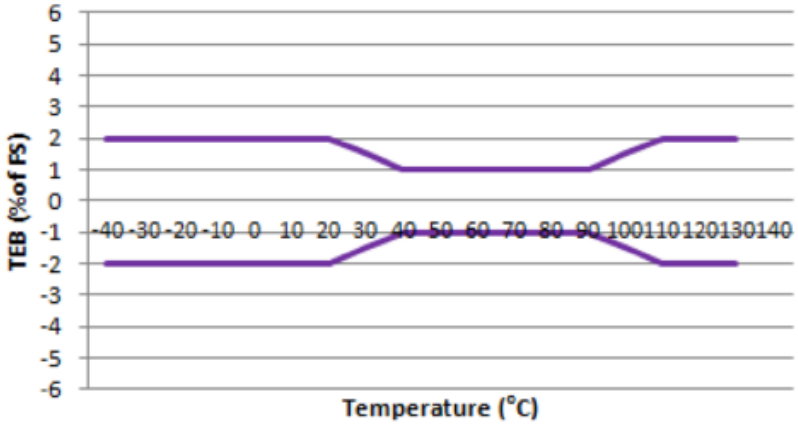
IT IS IMPORTANT THAT THE OUTPUT OF PRESSURE SENSOR VARIES VERY LITTLE WITH A CHANGE IN TEMPERATURE.

Temperature errors

- Thermal compensation is the process used to minimize errors due to temperature.
- ‘TEB’ is a method of describing the thermal performance of a pressure sensor.
- In this case the sensor output remains within a specified ‘band’ over the compensated temperature range.
- TEB is known as Thermal Error Band and Total Error Band
- **Total** Error Band includes ALL errors – zero and span settings, non-linearity and thermal errors. (Digital based sensors use TEB).

TEB

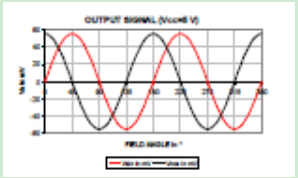
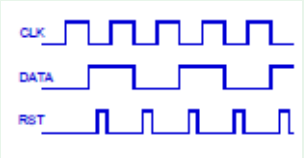
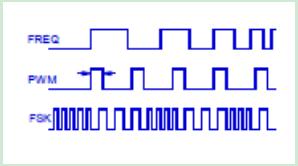

5V
0V
Error band
Eg. +/- 1%
Ideal sensor
0 psig
Full Scale psig


TEB (%of FS)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140
Temperature (°C)

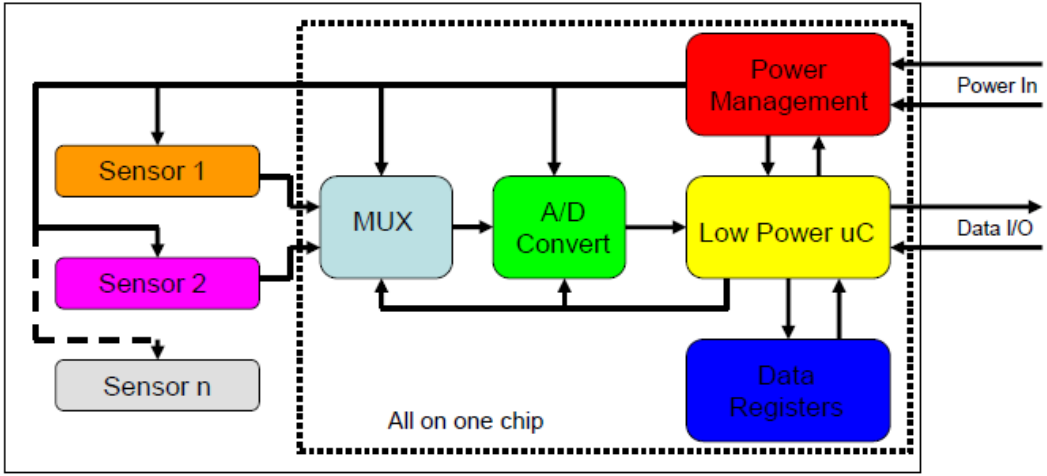
Other terms

- Proof Pressure – Pressure the sensor can be pressurised to without affecting the characteristics of the sensor (momentarily).
- Burst Pressure – Point at which the sensor diaphragm will be damaged.
  - Note: between the proof and burst pressure is a undetermined area. Can not guarantee long term affects.
- Common mode pressure – line pressure of the system.

Analogue and digital

TYPE	DEFINITION	EXAMPLES	WAVEFORMS
ANALOG	Output is a voltage, current or resistance whose magnitude represents the sensor reading.	0-100mV 0.5V-4.5V 4-20mA 100k ohm	
DIGITAL	Output is a series of 0's and 1's that form a binary word representing the sensor reading.	I^2C SPI RS-232 RS-485 Parallel data	
DIGITAL (TIME BASED)	Output is a digital signal with some timing feature that represents the sensor reading.	Frequency Out Pulse-width (PWM) Freq Shift (FSK) Sigma-delta (SDM)	

Anatomy of a digital sensor

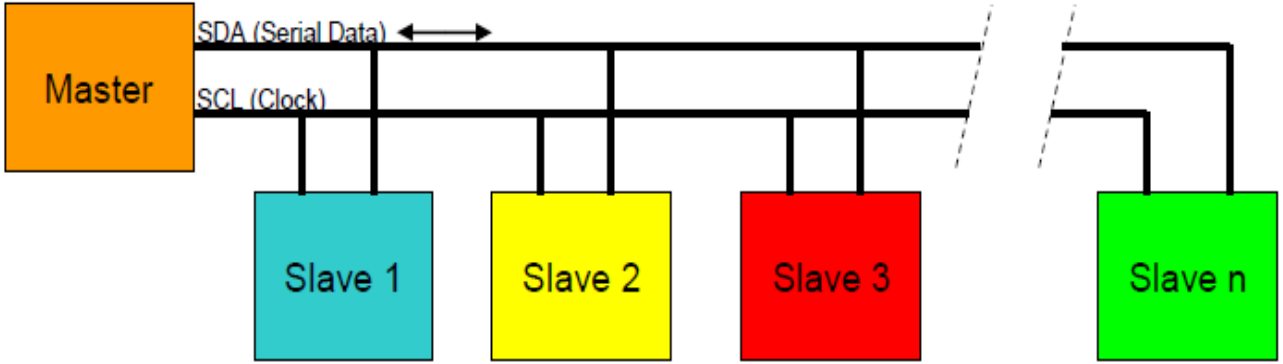


- All the functions except the sensor (pressure die) are typically embedded on a single chip.
- A temperature sensor is often included on the uC chip.
- Firmware to operate all the functions must be developed.
- The firmware is stored in non-volatile memory in the uC chip.

Common terminology in digital protocols

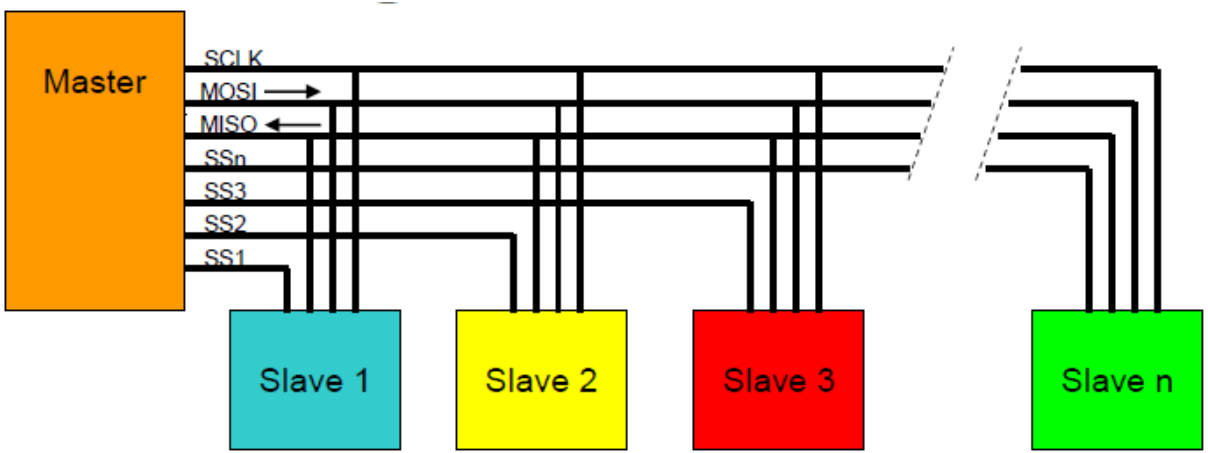
I^2C	**Inter Integrated Circuit** – A scheme where many devices can communicate digitally on a single pair of wires.
SPI	**Serial Peripheral Interface** – A scheme where many devices can communicate digitally on 4 wires. Faster than I^2C
Master	Usually a microcontroller that manages the communication with all the devices connected to an I^2C , SPI or any network
Slave	A device that is connected to the I^2C or SPI network, Examples are sensors, memory chips, displays, any peripheral
Bit	The smallest piece of digital information, usually represented by a “0” or a “1”. “0” = 0V. “1” = Vdd
Byte	A collection of 8 bits. Represents 0 to 255 in decimal numbers (256 different readings).
Serial Data	Digital 1’s & 0’s sent on a 0 1 0 1 0 0 1 0 1 1 0 line, one after another
Sleep Mode	The slave shuts down most internal operations and goes into a very low power condition, consuming microwatts & nanowatts

I2C communication



- Each Slave (Sensor) as a unique address. Selectable in datasheet.
- Master (uController) send a slave address and a request for data.
- All slaves hear the request. Only the addressed slave responds.
- The addressed slave sends out the requested data.
- The data travels on the SDA line in serial format (0's and 1's).
- The Master provides a clock signal (SCL) to control the timing of the data exchange.

SPI communication



- The Master (uController) enables a slave (sensor) via the slave select line (SS1….SSn).
- The Master sends commands to the slave via the MOSI (master out, slave in) line.
- The slave responds via the MISO (master in, slave out) line.
- Communication between master and slaves can occur simultaneously.
- The Master provides a clock signal (SCL) to control the timing of the data exchange

Digital sensor resolution

SEVERAL FACTORS AFFECT THE RESOLUTION OF A DIGITAL SENSOR:

- The sensing element itself (mems die) has a basic analogue resolution (usually infinite).
- The number of bits used to represent the reading, determines resolution.
- Oversampling will improve the resolution and S/N ratio.

BITS	COUNTS
8	128
9	256
13	4092
16	32736