intersema

MS5535A PRESSURE SENSOR MODULE

- **Integrated pressure sensor**
- **Pressure range 0-14 bar (200 PSI)**
- **15 Bit ADC**
- **6 coefficients stored on-chip for a software compensation**
- **3-wire serial interface**
- **1 system clock line (32.768 kHz)**
- **Low voltage / low power**

DESCRIPTION

The MS5535A is a SMD-hybrid device including a piezoresistive pressure sensor and an ADC-Interface IC.
It provides a 16 Bit data word from a pressure- and temperature-dependent voltage.
Additionally the module contains 6 readable coefficients for a highly accurate software calibration of the sensor.
MS5535A is a low-power, low-voltage device with automatic power down (ON/OFF) switching.
A 3-wire interface is used for all communications with a microcontroller.

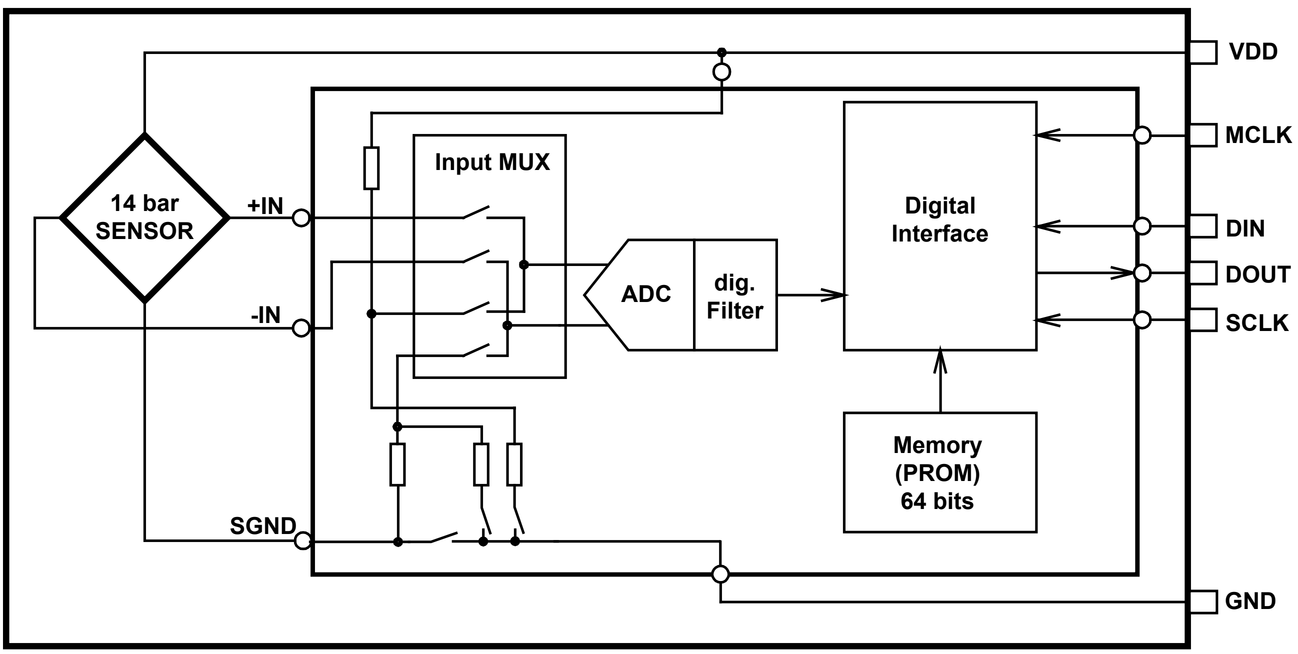
FEATURES

- 15 Bit ADC resolution
- Supply voltage 2.2 V to 3.6 V
- Low supply current
- -40°C to +60°C
- Small size
- No external components required

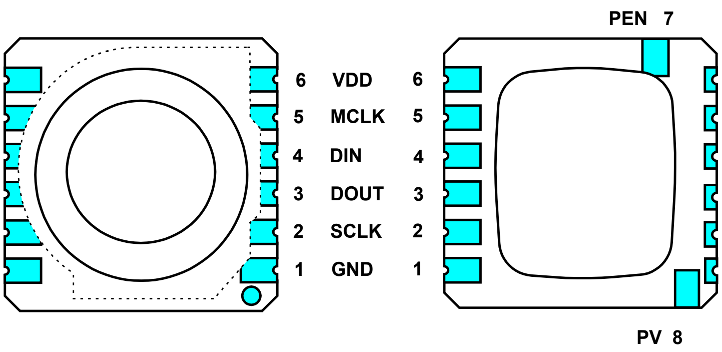
APPLICATION

- 15 Bit ADC resolution pressure measurement and control systems
- Mobile water depth measurement systems
- Diving computers and divers watches

BLOCK DIAGRAM



PIN CONFIGURATION



PIN DESCRIPTION

Pin Name	Pin	Type	Function
GND	1	G	Ground
SCLK	2	I	Serial Data Clock
DOUT	3	O	Data Output
DIN	4	I	Data Input
MCLK	5	I	Master Clock
VDD	6	P	Positive Supply Voltage
PEN	7	I	Programming Enable
PV	8	N	Negative Programming Voltage

Note: Pins 7 (PEN) and 8 (PV) are only used by the manufacturer for calibration purposes.

ABSOLUTE MAXIMUM RATINGS

Parameter	Symbol	Conditions	Min	Max	Unit
Supply Voltage	V_{DD}		-0.3	4	V
Overpressure	P			30	bar abs
Storage Temperature	T_{Stg}		-45	+70	°C

Note: Storage and operation in an environment of dry and non-corrosive gases.

RECOMMENDED OPERATING CONDITIONS

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Supply Voltage	V_{DD}		2.2	3.0	3.6	V
Supply Current, average (1) during conversion (2) standby (no conversion)	 I_{avg} I_{SC} I_{ss}	V_{DD} = 3.0 V		 5 1 	 0.5	 µA mA µA
Current consumption into MCLK (3)		MCLK=32768Hz			0.5	µA
Operating pressure range	p		0		14	bar abs.
Operating temperature range	T_a		-40	+25	+60	°C
Conversion time	T_{conv}	MCLK=32768Hz			35	ms
External clock signal (4)	MCLK		30000	32768	35000	Hz
Duty cycle of MCLK			40/60	50/50	60/40	%
Serial Data Clock	SCLK				500	kHz

Notes:

1. Under the assumption of one conversion every second. Conversion means either a pressure or a temperature measurement started by a command from the serial interface of MS5535A.

2. During conversion the sensor will be switched on and off in order to reduce power consumption; the total ON time within a conversion is about 2ms.

3. Switching off MCLK while MS5535A is in standby mode can reduce this value.

4. It is strongly recommended that a crystal oscillator be used because the device is sensitive to clock jitter. A square-wave form of the clock signal is a must.

5. Reliable operation requires protection of the pressure sensor from direct contact with light.

6. **Power supply pins (VDD, GND) shall be decoupled with a tantalum (47µF) capacitor to achieve highest accuracy of the circuit.**

ELECTRICAL CHARACTERISTICS

◆ Digital inputs

(T=-40°C .. 60°C)

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Input High Voltage	V_{IH}	V_{DD} = 2.2…3.6V	80% V_{DD}		100% V_{DD}	V
Input Low Voltage	V_{IL}	V_{DD} = 2.2…3.6 V	0% V_{DD}		20% V_{DD}	V
Signal Rise Time	t_R			200		ns
Signal Fall Time	t_f			200		ns

◆ Digital outputs

(T=-40°C .. 60°C, V_{DD} = 2.2V..3.6V)

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Output High Voltage	V_{OH}	I_{Source} = 0.6 mA	75% V_{DD}		100% V_{DD}	V
Output Low Voltage	V_{OL}	I_{Sink} = 0.6 mA	0% V_{DD}		20% V_{DD}	V
Signal Rise Time	t_r			200		ns
Signal Fall Time	t_f			200		ns

◆ AD-converter

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Resolution (1)				15		bit
Conversion Time					35	ms
Accuracy (2)				± 2	± 7	LSB

Notes:

1. The ADC output range is from 5,000 counts to 37,000 counts, thus requiring a 16 Bit output word.
2. Accuracy limited by the non-linearity of the ADC.

PRESSURE OUTPUT CHARACTERISTICS

With the calibration data provided by the MS5535A system (stored in the interface IC) the following characteristics can be achieved:

Parameter	Symbol	Conditions	Min	Typ	Max	Unit	Note
Resolution				1.2		mbar	1
Absolute Pressure Accuracy		p = 0..5 bar p = 0..10 bar p = 0..14 bar Temp.range 0... +50°C	-25 -60 -160		+20 +20 +20	mbar mbar mbar	2
		p = 0..5 bar p = 0..10 bar p = 0..14 bar Temp.range -40... +60°C	-60 -60 -160		60 140 150	mbar mbar mbar	2
Maximum Error over Temperature		T_a = - 40…+60°C p = const.	-160		+150	mbar	3
Long-term Stability		6 month		20		mbar	4
Maximum Error over Supply Voltage		VDD = 2.2…3.6V	-20	0	+20	mbar/V	

Notes:

1. A stable pressure reading of the given resolution requires taking the average of 4 to 8 subsequent pressure values due to noise of the ADC. A better resolution can be obtained with more averaging.

2. Maximum error of pressure reading over the pressure range.

3. Maximum error of temperate reading over the temperature range at constant pressure.

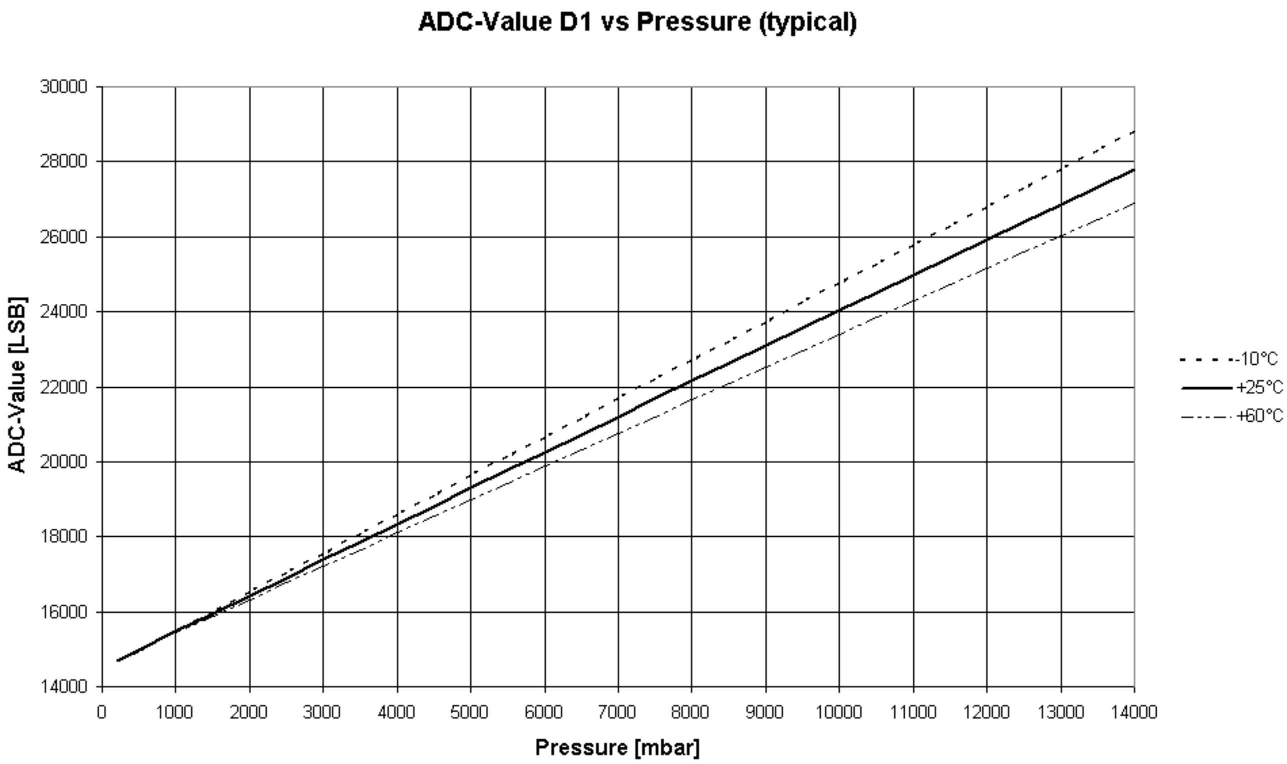
4. The long-term stability is measured with non-soldered devices

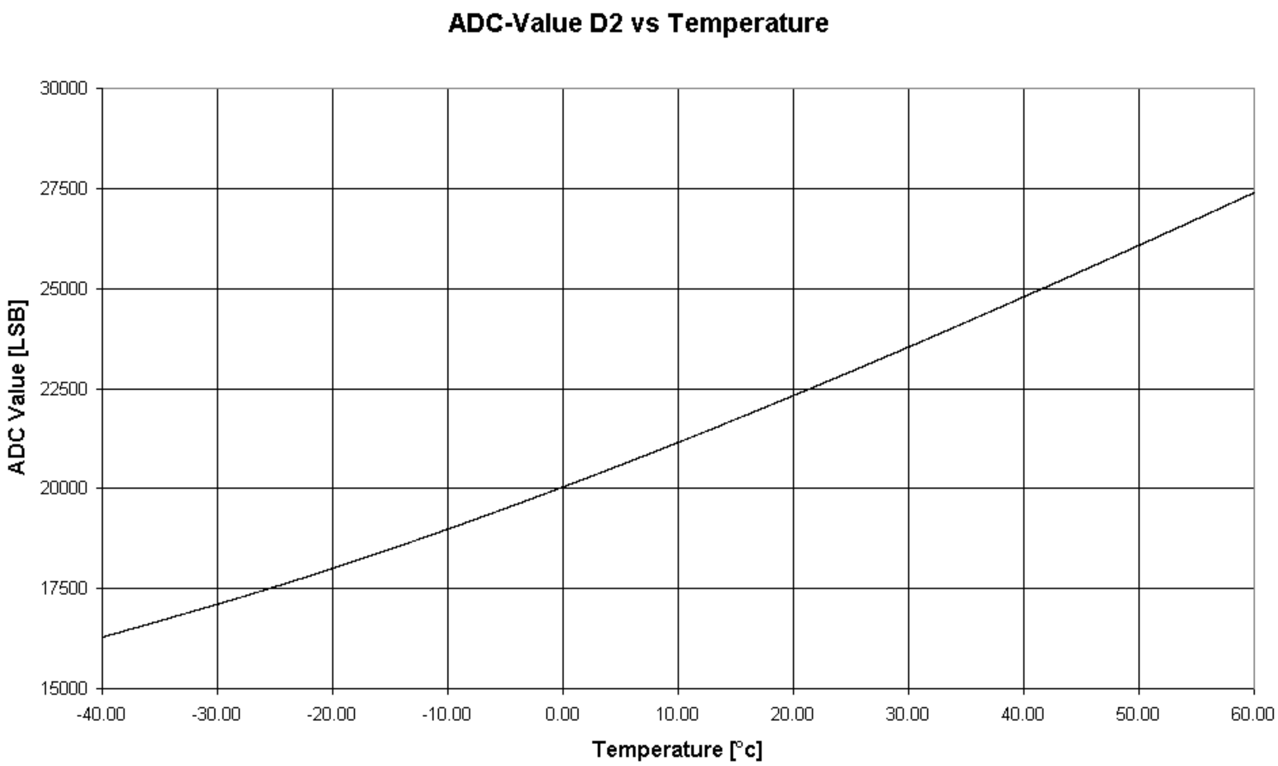
TEMPERATURE OUTPUT CHARACTERISTICS

This temperature information is not required for most applications, but it is necessary to allow for temperature compensation of the pressure output. The reference temperature is 25°C.

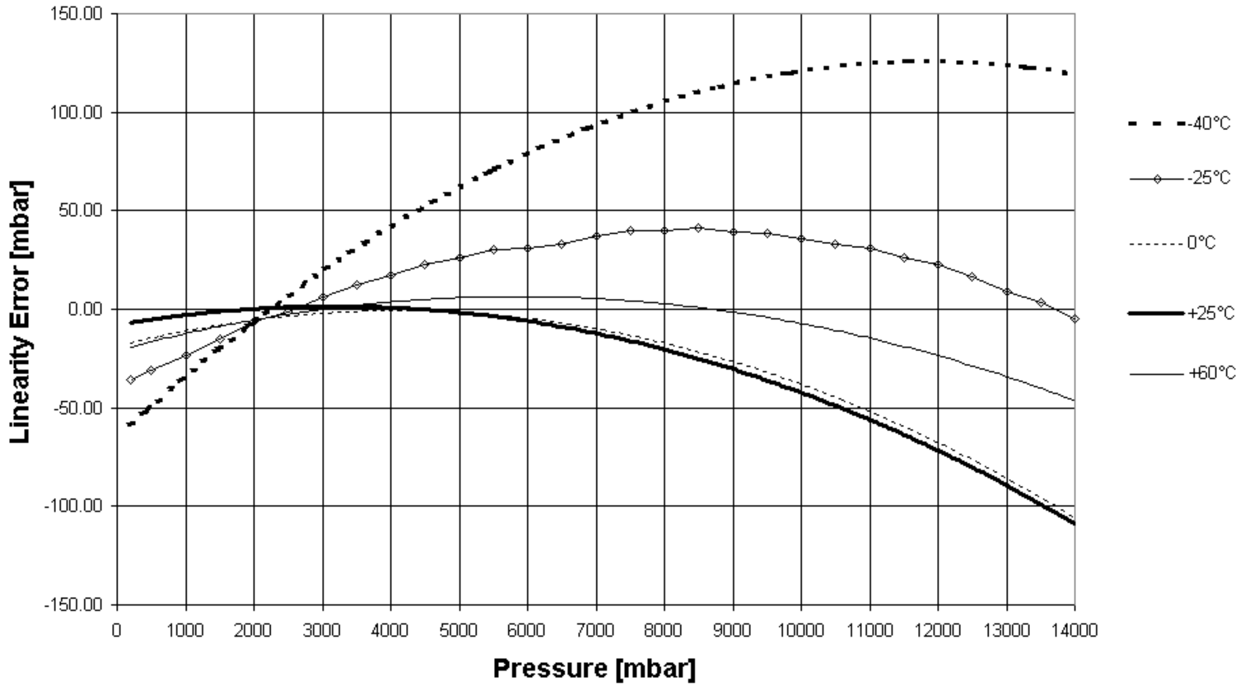
Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Resolution			0.005		0.015	°C
Accuracy		at reference temperature	-0.8		0.8	°C
Maximum Error over Supply Voltage		VDD = 2.2…3.6V	-0.3		+ 0.3	°C/V

TYPICAL PERFORMANCE CURVES

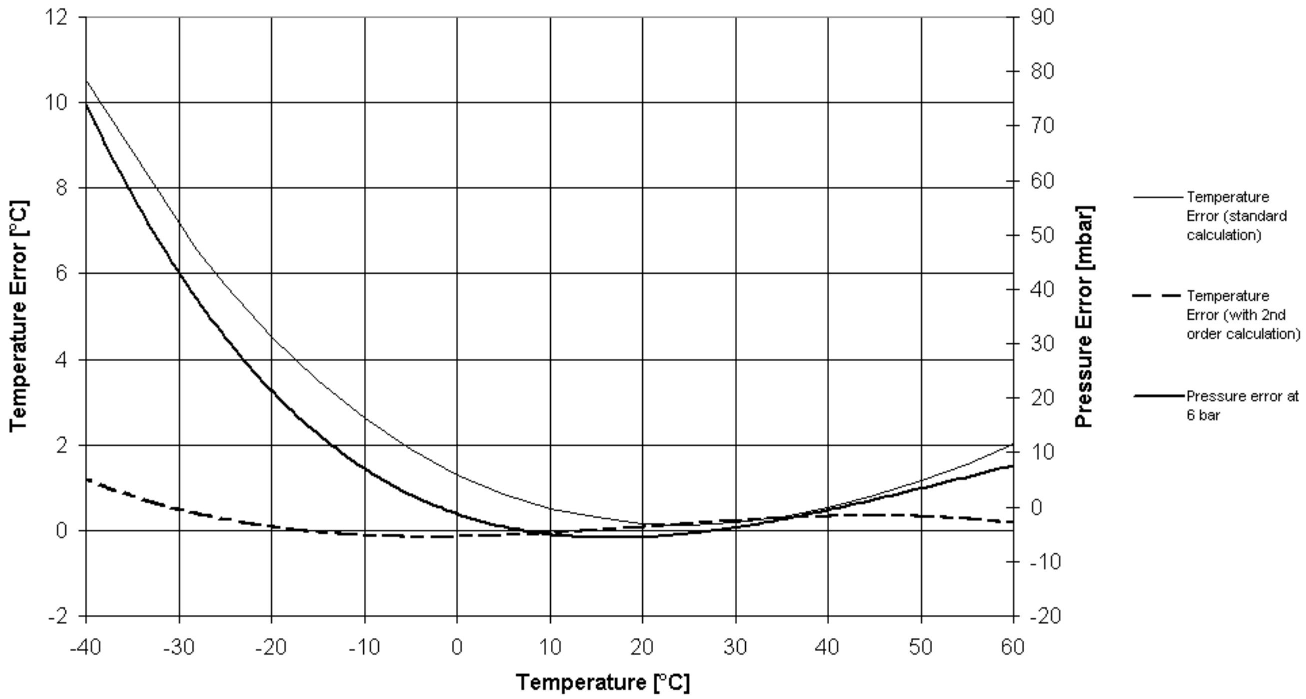


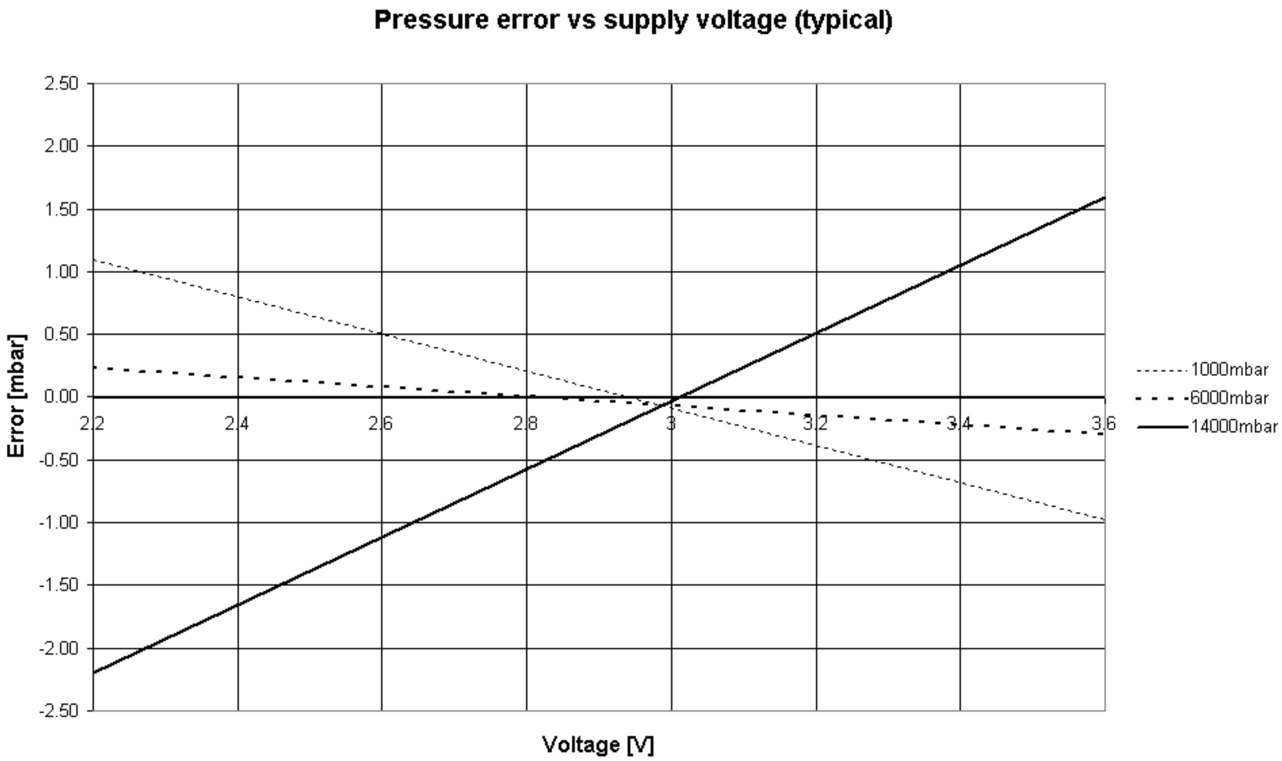


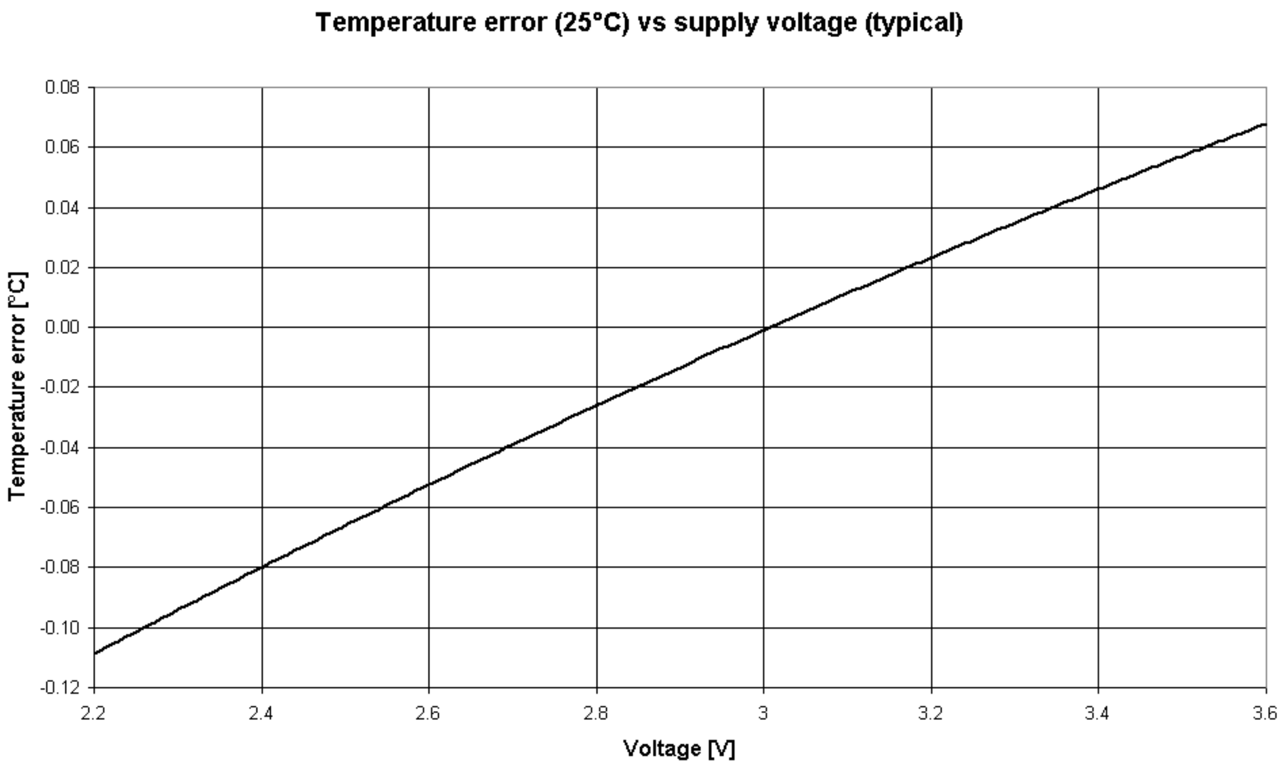
Absolute Pressure Accuracy after Calibration (typical)



Accuracy vs temperature (typical)




Pressure error vs supply voltage (typical)
Error [mbar]
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
2.2
2.4
2.6
2.8
3
3.2
3.4
3.6
1000mbar
6000mbar
14000mbar
Voltage [V]


Temperature error (25°C) vs supply voltage (typical)
Temperature error [°C]
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08
-0.10
-0.12
2.2
2.4
2.6
2.8
3
3.2
3.4
3.6
Voltage [V]

FUNCTION

◆ General

The MS5535A consists of a piezoresistive sensor and a sensor interface IC. The main function of the MS5535A is to convert the uncompensated analog output voltage from the piezoresistive pressure sensor into a 16 Bit digital value, as well as providing a 16 Bit digital value for the temperature:

- measured pressure (16 bit) "D1"
- measured temperature (16 bit) "D2"

As the output voltage of a pressure sensor is strongly dependent on temperature and process tolerances, it is necessary to compensate for these effects. This compensation procedure must be performed by software using an external microcontroller. This procedure is written as an easy-to-use and easy-to-program routine (only with addition, subtraction and multiplication).

◆ Factory calibration

The module is calibrated at two temperatures (T1 = 10°C and T2 = 35°C), and two pressures (P1 = 1000 mbar and P2 = 6000 mbar). The MS5535A carries also 6-bit PROM memory, which is subdivided in four 16bit words that store the compensation information in the form of 6 coefficients.

◆ Pressure and temperature measurement

The sequence of reading pressure and temperature as well as of performing the software compensation is depicted in flow chart, Fig. 1.

First the WORD1 to WORD4 have to be read through the serial interface. This can be done once after reset of the microcontroller that interfaces to the MS5535A. Afterwards the compensation coefficients C1 to C6 must be decoded (see WORD1 to WORD4 pattern, Fig. 2).

For the pressure measurement the microcontroller has to read the 16-bit values for pressure (D1) and temperature (D2) via the serial interface in a loop (for instance every 1 sec.). Then, the real pressure is calculated out of D1, D2 and C1 to C6 according to the formula in Fig. 1. All calculations can be handled with 16-bit variables. Intermediate results may be 32 bits long where only the upper 16 Bit are significant. Divisions can be made by bit-wise shifting (divisors are to the power of 2) and results of divisions can be handled as type integer if the calculations are done in the order as recommended in Figs. 1 and 3.

For the timing of signals to read out WORD1 to WORD4, D1, and D2 please refer to the paragraph "Serial Interface".

◆ Measurement principle

For both the pressure and temperature measurement, the same ADC is used (sigma delta converter):

- for the pressure measurement, the differential output voltage from the pressure sensor is converted
- for the temperature measurement, the sensor's bridge resistor is sensed and converted

During both measurements the sensor will only be switched on for a very short time in order to reduce power consumption. The A/D converter has been optimised to work in the linear range (numeric values in range [5,000:37,000]) for all sensor variations in the specified range of temperature and pressure.

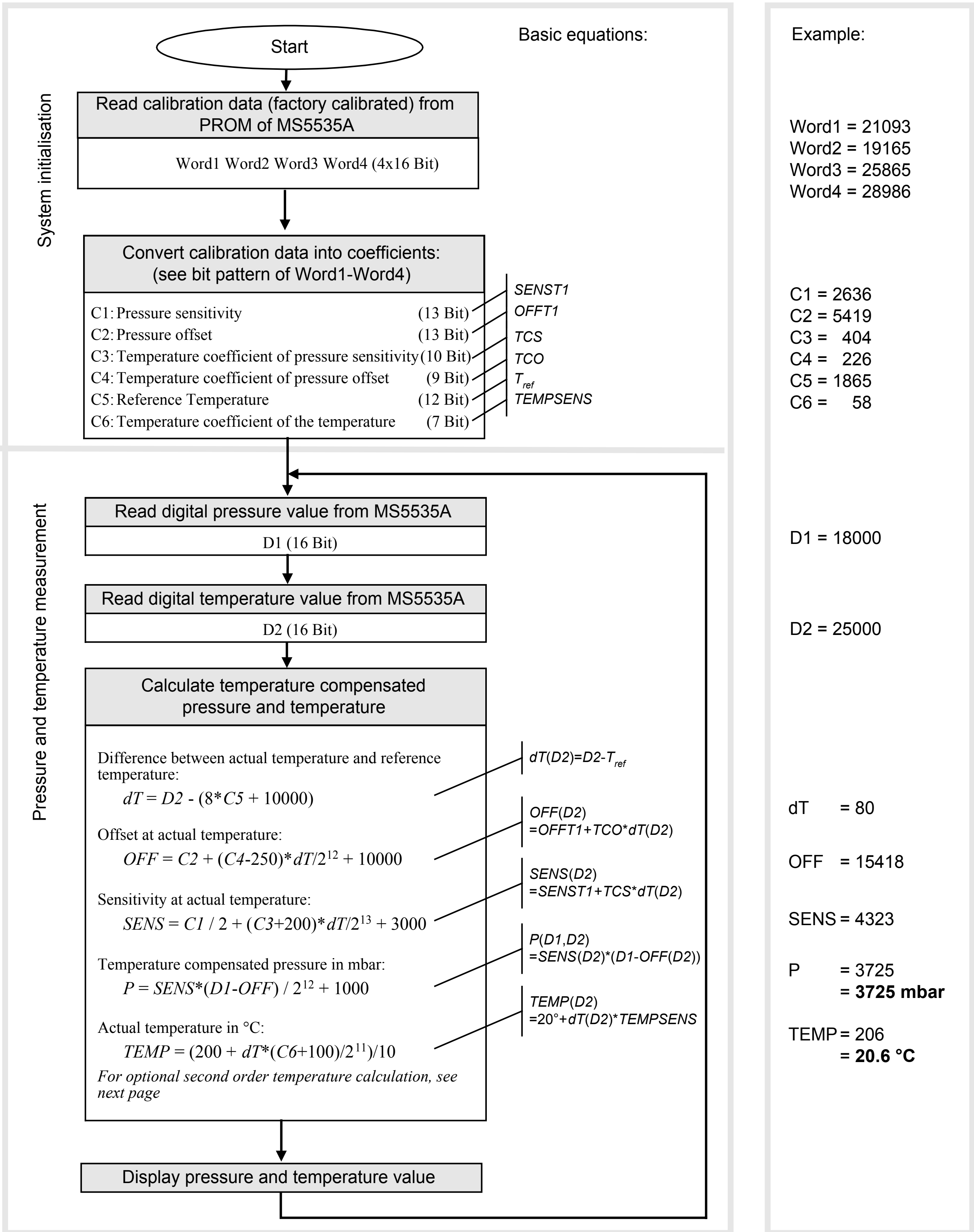


Figure 1: Flow chart for pressure/temperature reading and software compensation.

Notes:

1. Readings of D2 can be done less frequently, but the display will be less stable in this case
2. For a stable display of 1 mbar resolution, it is recommended to display the average of 4 to 8 subsequent pressure values.

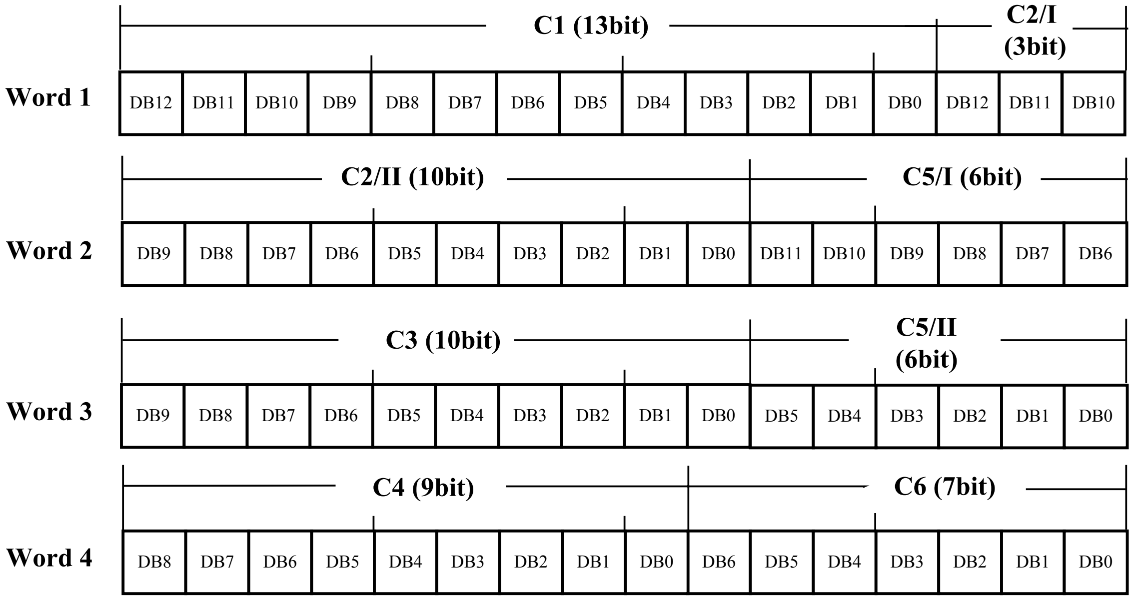


Figure 2: Arrangement (bit pattern) of calibration data in Wort1 to Word4.

◆ Second-order temperature calculation

In order to obtain full temperature accuracy over the whole temperature range, it is recommended to compensate for the non-linearity of the output of the temperature sensor. This can be achieved by the second-order temperature calculation, i.e. by replacing the “TEMP” equation given in fig. 1 by the small algorithm given hereafter. The calculation of the temperature compensated pressure as shown in Fig. 1 is **not affected** by this second-order calculation.

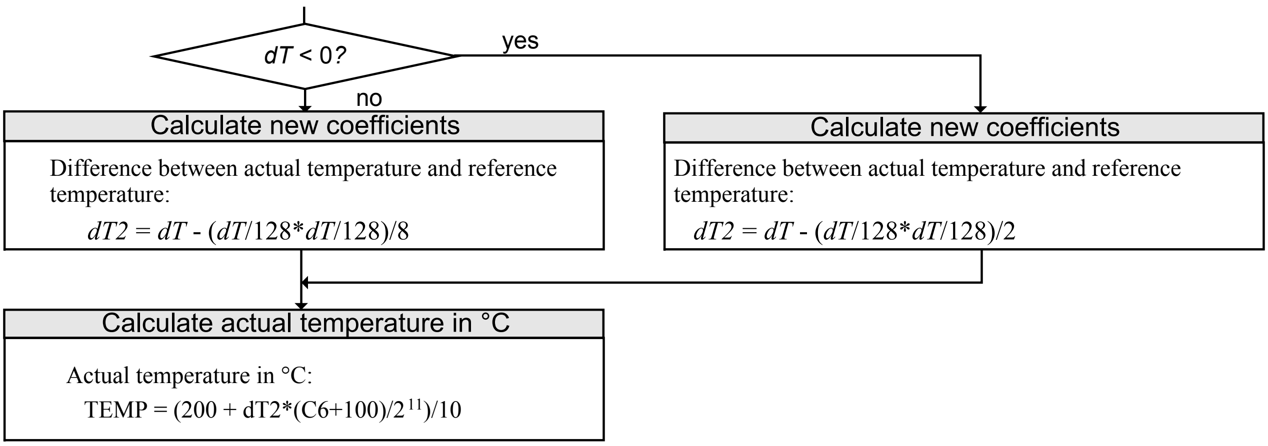


Figure 3: Second-order temperature calculation

◆ Serial interface

The MS5535A communicates with microprocessors and other digital systems via a 3-wire serial interface as shown in Figure 1. The SCLK (Serial Clock) signal initiates the data transfer and synchronizes the data transfer with each bit being transmitted on the falling edge of SCLK and each bit being received on the rising edge of SCLK. This signal will be generated by the microprocessor's system. The signal DOUT (Data Out) indicates the data transmission status and the conversion status. The digital data that is provided on the DOUT pin is either the conversion result or the software calibration data. The selection of the output data is dependent on the data format of the DIN (Data Input) signal.

Following is a list of possible output data instructions:

- Conversion start for pressure measurement and ADC-data-out "D1" (Figure 4a)
- Conversion start for temperature measurement and ADC-data-out "D2" (Figure 4b)
- Calibration data read-out sequence for word 1 and word 3 (Figure 4c)
- Calibration data read-out sequence for word 2 and word 4 (Figure 4d)
- RESET sequence (Figure 4e)

Every communication starts with a instruction sequence at pin DIN. Figure 4 shows the timing diagrams for the MS5535A. The device does not need a "Chip select" signal. Instead of this, there is a start-sequence (3 bits high) and a stop-sequence (3 bits low) for each reading. The Start Sequence is followed by 4 instruction bits that select either a pressure/temperature reading or a reading of the calibration data. The module acknowledges the start of a conversion by a low to high transition on pin DOUT during the last bit of the stop-sequence.
A minimum of two additional clocks at SCLK is required after the acknowledge signal.
The end of a conversion is indicated by a high to low transition on DOUT. This signal can be used to create an interrupt for the microcontroller. The microcontroller may now read out the 16-bit word by giving another 16 clocks on the SLCK pin. Data is valid at the falling edge at SLCK.

It is important to always read out the last conversion result before starting a new conversion.

It is recommended to send the RESET-sequence before each acquisition sequence to avoid hanging up the protocol permanently in case of electrical distortions.

It is possible to interrupt the data read-out sequence with a hold of the SCLK signal.
The RESET-sequence sets the internal control logic into the start-up state.
This sequence is 21 bits long. The DOUT signal might change during that sequence (see figure 4e).

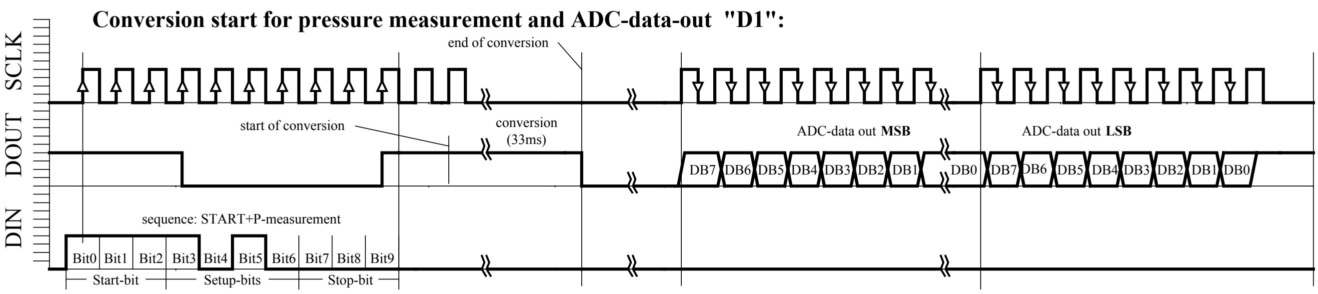


Figure 4a: D1 acquisition sequence

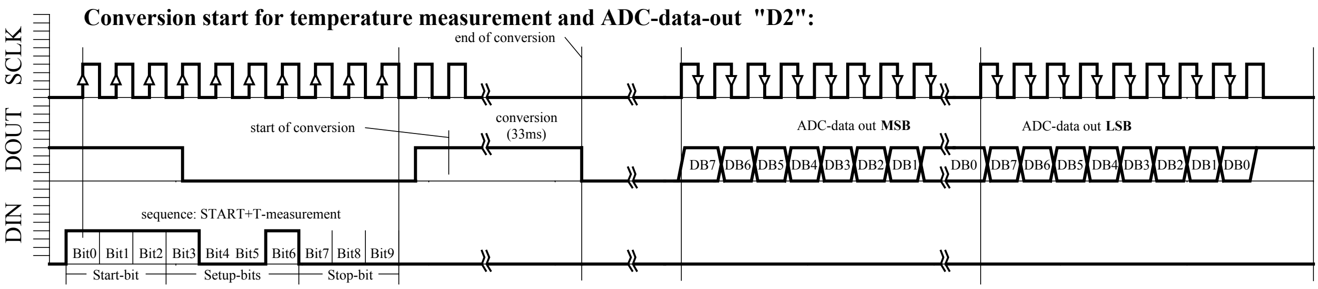


Figure 4b: D2 acquisition sequence

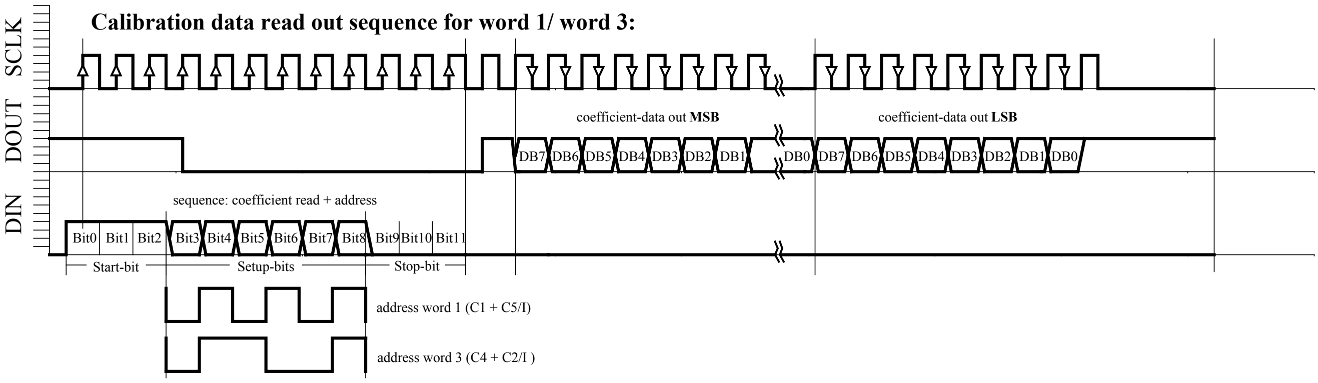


Figure 4c: W1, W3 reading sequence

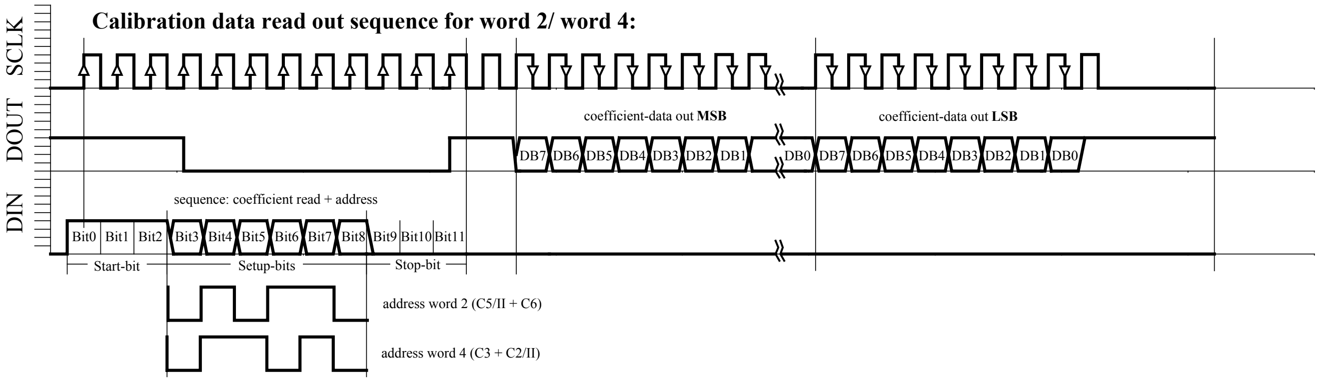


Figure 4d: W2, W4 reading sequence

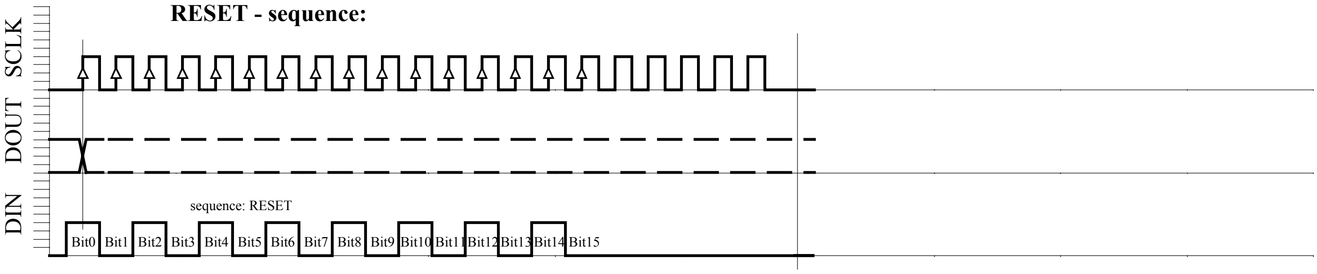


Figure 4e: Reset sequence (21 bits)

APPLICATION INFORMATION

- **GENERAL**

The idea of combining a sensor directly with an adapted integrated circuit is to save other external components and to achieve very low power consumption. The main application field for this system includes portable devices with battery supply, but its high accuracy and resolution makes it also well suited for industrial and automotive applications. The possibility to compensate the sensor by software allows the user to adapt it to its particular application. Communication between the MS5535A and the widely available microcontrollers is realized over an easy-to-use 3-wire serial interface. Customers may select which microcontroller system to be used, since there are no specific interface cells required. This may be of interest for specially designed 4 Bit-microcontroller applications.

Storage of calibration data in the device is done during the module's final test. Automatic test equipment is used to perform tests under pressure and temperature and to calculate individual coefficients for every sensor, thus allowing a highly accurate compensation.
Further, since the calibration data is stored in the MS5535A, the user can save additional external memory in his microcontroller system (i.e. EEPROM).

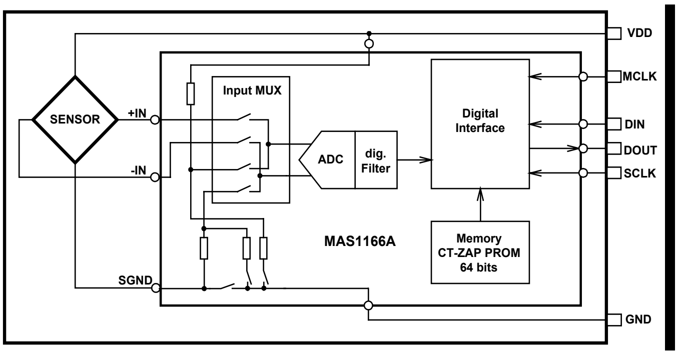
The MS5535A is mounted on a ceramic substrate. AgPd connection pads ensure the soldering of the substrate and automatic assembly. Standard surface mount techniques can be used (IR reflow soldering technique at temperatures not exceeding 225° C for 30 sec is recommended). A dot on the ceramic substrate marks pad 1. The MS5535-AM carries a metal protection cap. The package outline of the module allows the use of a flexible PCB to connect it. This can be important for applications in watches and other special devices, and will also reduce mechanical stress on the device.

For applications subject to mechanical shock, it is recommended to enhance the mechanical reliability of the solder junctions by covering the rim or the corners of MS5535A's ceramic substrate with glue or glob top-like material.

- **SYSTEMS USING MS5535A**

MS5535A is a circuit that can be used in connection with a microcontroller in divers computer applications. It is designed for low-voltage systems with a supply voltage of 3V, especially in battery applications. The MS5535A is optimised for low current consumption as the AD-converter clock (MCLK) can use the 32.768kHz frequency of a standard watch crystal, which is supplied in most portable watch systems.

For applications in combined divers/altimeter systems Intersema can deliver a simple formula based on a linear interpolation, where the number of interpolation points influences the accuracy of the formula.



Advantages of MS5535A:
- easy layout (one side contact for flexible PCB)
- better reliability
- reduced test time
- universal to use, less development time
- high compensation accuracy because of individual sensor test
- lower price as a solution with sensor, amplifier, AD-converter and external parts
- easy-to-use 3 wire serial interface

Figure 5: Block diagram of MS5535A

• APPLICATION EXAMPLES

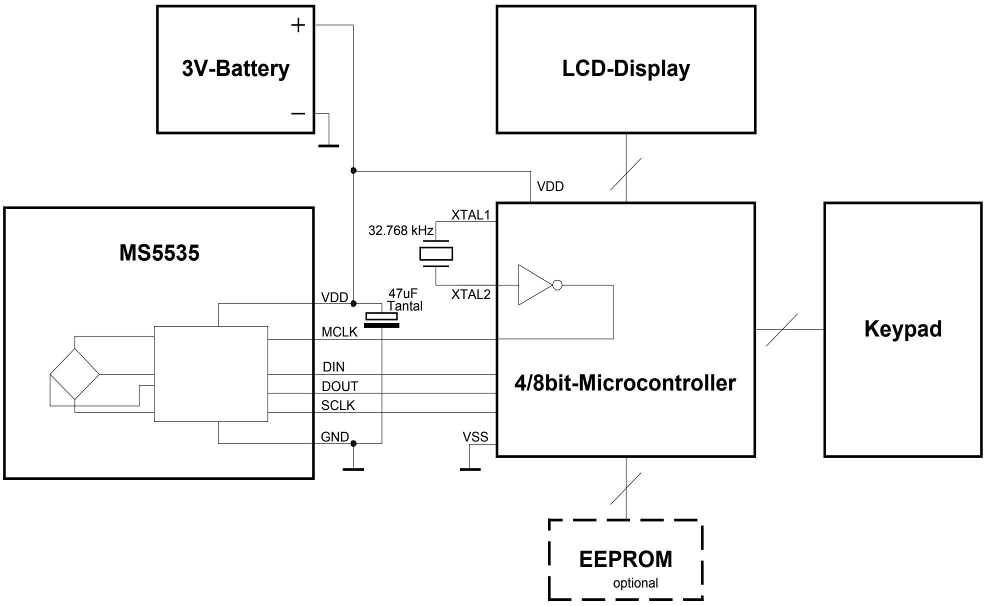


Figure 6: Demonstration of MS5535A in a diving computer

• Profile for soldering MS5535A

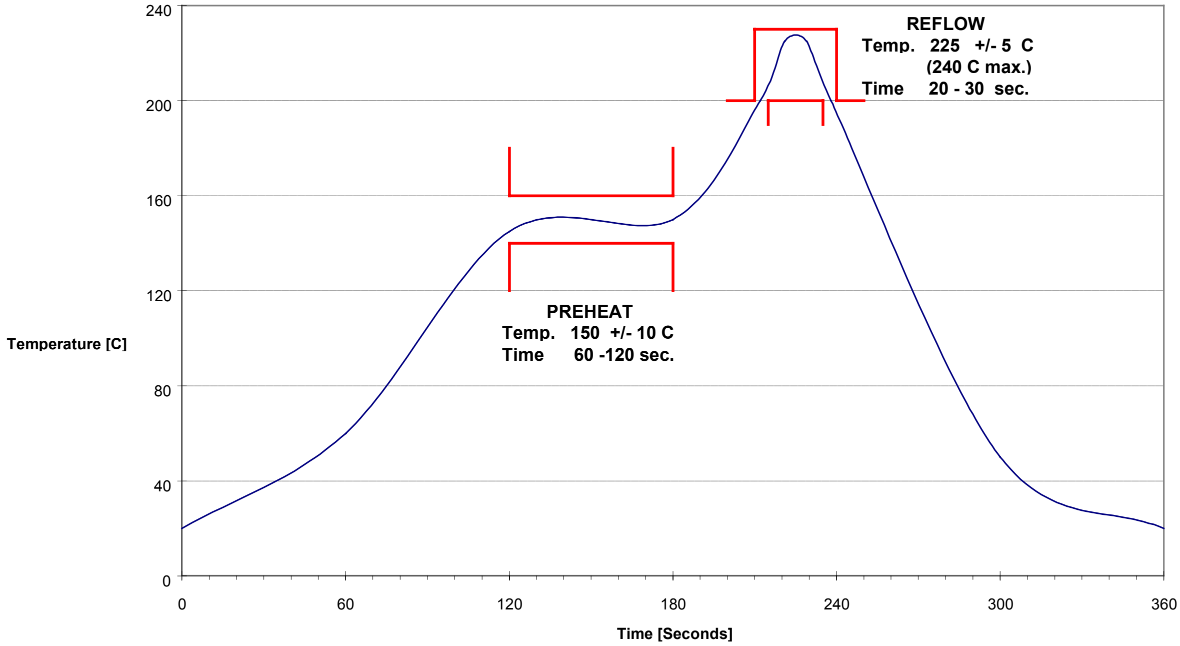
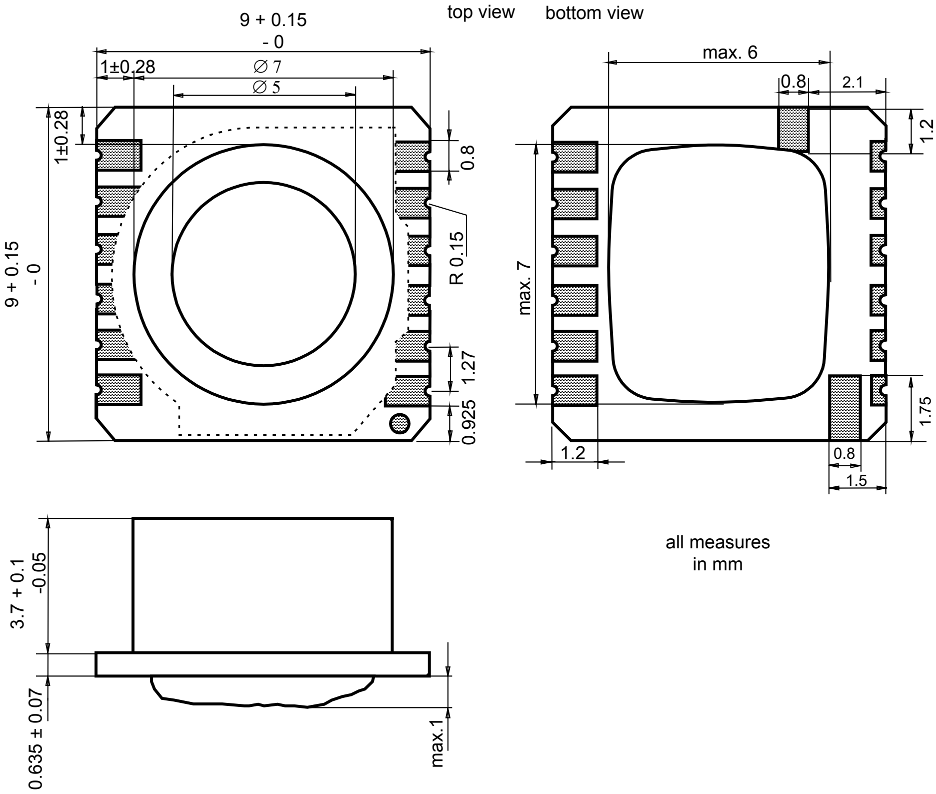


Figure 7: Recommended soldering profile

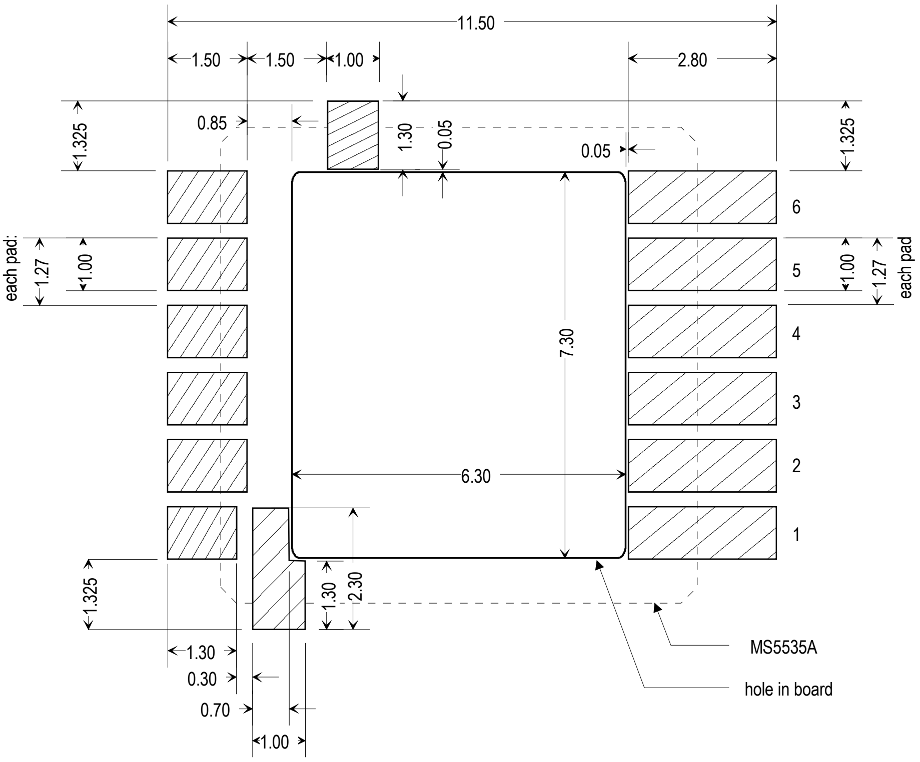
DEVICE PACKAGE OUTLINES

- **MS5535-AM**

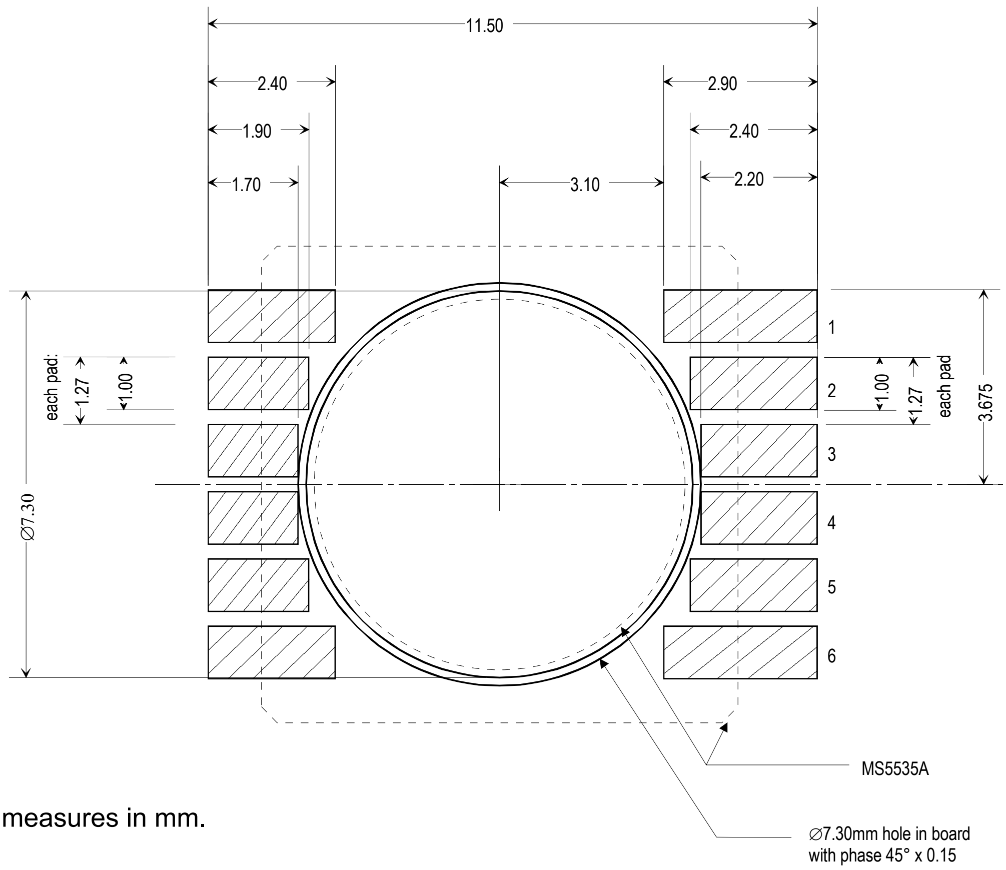


RECOMMENDED PAD LAYOUT

- **Pad layout for bottom side of MS5535A soldered onto printed circuit board**



- **Pad layout for topside of MS5535A soldered onto printed circuit board**



All measures in mm.

ASSEMBLY

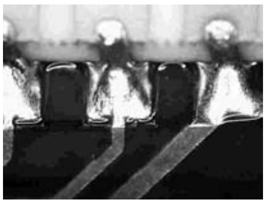
▪ Solder Paste

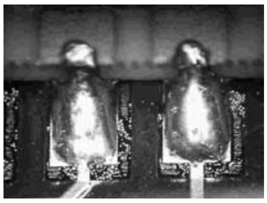
The MS5535A is a ceramic device that requires special assembly considerations compared to the assembly of SMD leaded components. The connecting pads are made of AgPd (Silver Palladium) pads. Like for other ceramic devices the sensor must be soldered with Sn62Pb36Ag2 Solder paste. This solder paste contains 2% of silver, which avoids silver migration from the AgPd pad into the solder paste. The melting point of this paste is slightly lower (179°C) than the standard Sn63Pb37 solder paste.

DO NOT USE SN63PB37 Solder Paste for soldering MS5535A !

▪ Soldering Quality

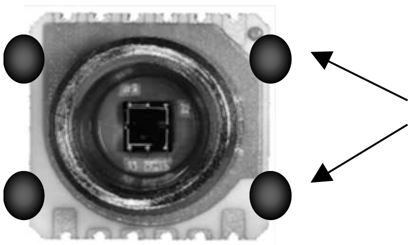
A good solder connection should look like shown on the photo to the below left forming a slight angle and filling the via almost to the top. **DO ALWAYS SOLDER BY REFLOW** using the recommended reflow profile. Soldering by hand will in most cases result in overheating of the device due to the good thermal conductivity of the ceramic. It is recommended to optimize the profile attaching a thermocouple to the sensor. Too low temperature will result in incomplete soldering resulting in a much less strong connection to the PCB as can be seen on the photo below right. For prototyping purposes cables can be soldered to the solder bumps on the backside of the sensor. The cable should be very thin to avoid lifting off the contact pad from the ceramic. Wire wrap cables will normally do a good job.


Good Solder Contact


Bad Solder Contact

▪ Mechanical Stress

It is recommended to avoid mechanical stress on the PCB on which the sensor is mounted. The thickness of the PCB should not be below 1.6mm. A thicker PCB is more stiff, creating less stress on the soldering contacts. For applications where mechanical stress cannot be avoided (for example ultrasound welding of the case or thin PCBs in watches) please fix the sensor with drops of low stress epoxy (for example Hysol FP-4401) at the corners of the sensor as shown below.

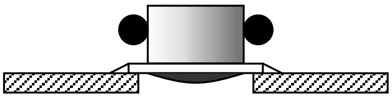


Fixing with Globtop increases mechanical stability

ASSEMBLY

- **Sealing with O-Ring**

In products like diving computers, the electronics must be protected against direct water or humidity. For those products the MS5535-AM provides the possibility to seal with an O-Ring. The protective cap of the MS5535-AM is made of special anticorrosive stainless steel with a polished surface. In addition to this the MS5535-AM is filled with silicone gel (depending of the product) covering the sensor and the bonding wires. The O-Ring (or O-Rings) shall be placed at the outer diameter of the metal cap. This method avoids mechanical stress since the sensor can move in vertical direction.



- **Cleaning**

The MS5535A has been manufactured under cleanroom conditions. Each device has been inspected for the homogenity and the cleaningness of the silicone gel. It is therefore recommended to assemble the sensor under class 10’000 or better conditions. Should this not be possible, it is recommended to protect the sensor opening during assembly from entering particles and dust. To avoid cleaning of the PCB, solder paste of type “No-Clean” shall be used.
CLEANING MIGHT DAMAGE THE SENSOR.

- **ESD Precautions**

The electrical contacts (except programming pads) are protected against ESD according to 2KV HBM (human body model). The programming pads are more sensitive due to the nature of the OTP programming cells that store the calibration coefficients. The breakdown voltage of PEN and PV is 800V typical. It is therefore essential to ground machines and personal properly during assembly and handling of the device. The MS5535A is shipped in antistatic transport boxes. Any test adapters or production transport boxes used during the assembly of the sensor shall be of an equivalent antistatic material.

ORDERING INFORMATION

Product Code	Product	Package	Comments
MS5535-AM	Pressure Sensor Module with gel	SMD hybrid with solder paste, metal protection cap, silicon gel sensor protection	standard version
MS5535-AM	Pressure Sensor Module without gel	SMD hybrid with solder paste, metal protection cap	standard version

FACTORY CONTACTS

Intersema Sensoric SA
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