

MS5534

BAROMETER MODULE

Preliminary

- Integrated pressure sensor
- Pressure range 300-1100 mbar
- 15 Bit ADC
- 6 coefficients for a software compensation stored on-chip
- 3-wire serial interface
- 1 system clock line (32.768 kHz)
- Low voltage / low power

DESCRIPTION

The MS5534 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. MS5534 is a low-power, low-voltage device with automatic power down (ON/OFF) switching. A 3-wire interface will be used for all communications with a microcontroller.

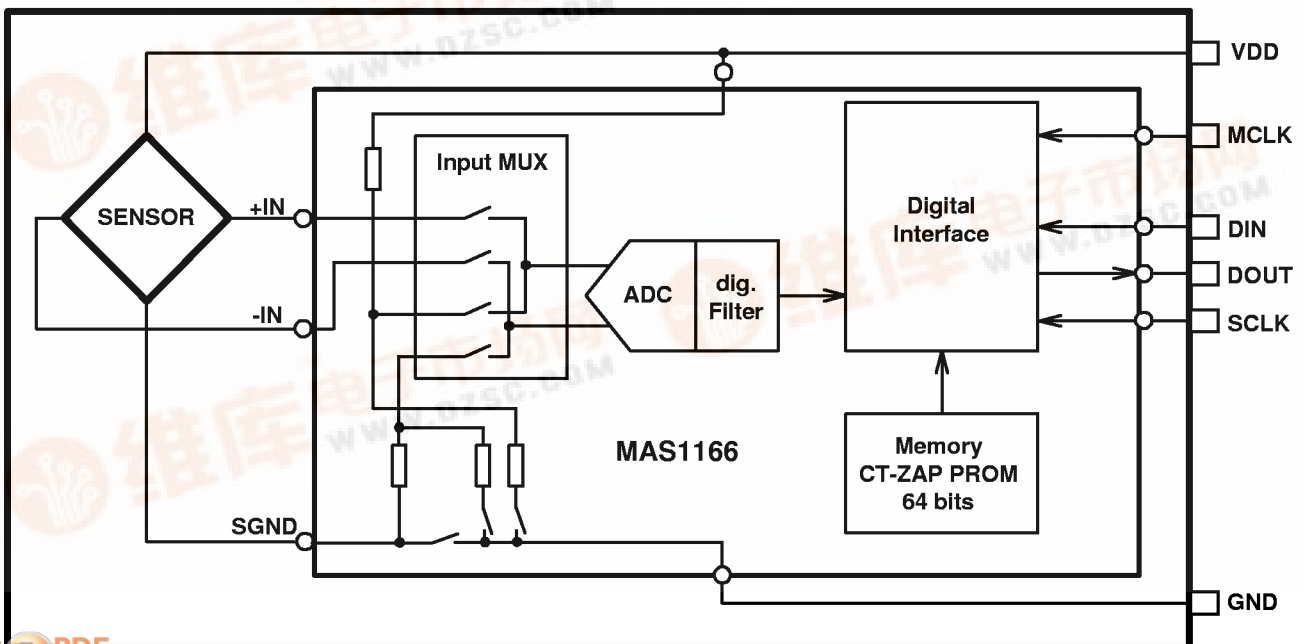
FEATURES

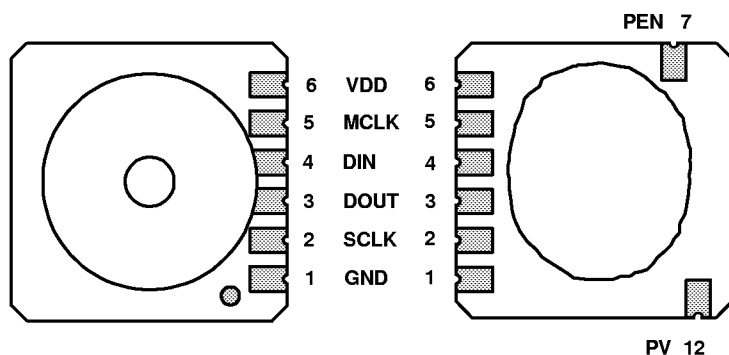
- 15 Bit ADC resolution
- Supply voltage 2.2 V to 3.6 V
- Low supply current
- -10°C to +60°C
- Small size
- No external components required

APPLICATION

- 15 Bit ADC resolution pressure measurement and control systems
- Mobile altimeter/barometer systems
- Weather control systems
- Adventure or multi-mode 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	12	N	Negative Programming Voltage

Note: Pins 7 (PEN) and 12 (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			4	bar abs
Storage Temperature	T_{Sig}		-20	+70	°C

NOTE: Power supply pins (VDD, GND) should be decoupled with a tantalum (47 μ F) capacitor to achieve best circuit performance.

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 (power down)	I_{avg} I_{SC} I_{SS}	$V_{DD} = 3.0\text{ V}$		5 1	0.5	μA mA μA
Operating pressure range	p		300		1100	mbar abs.
Operating temperature range	T_a		-10	+25	+60	$^{\circ}\text{C}$
Conversion time	T_{conv}	MCLK=32768Hz			35	ms
External clock signal (3)	MCLK		30000	32768	35000	Hz
Delay after conversion (4)	T_{del}	MCLK=32768Hz	0.1		100	ms
Duty cycle of MCLK			60/40	50/50	40/60	%
Serial Data Clock	SCLK				500	kHz

Notes:

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

- Under the assumption of one pressure measurement and one temperature measurement every second
- 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
- It is strongly recommended that a crystal oscillator be used because the device is sensitive to clock jitter
- T_{del} is the time between the falling edge of DOUT (indicating the end of conversion) and the start of data read-out.

ELECTRICAL CHARACTERISTICS
◆ Digital inputs

 (T=-10 $^{\circ}\text{C}$.. 60 $^{\circ}\text{C}$)

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

ELECTRICAL CHARACTERISTICS

◆ Digital outputs

 (T=-10°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	80% 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				15		bit
Conversion Time					35	ms
Accuracy					1	LSB

Note: The ADC output range is from 5,000 counts to 37,000 counts, thus requiring a 16 Bit output word.

PRESSURE OUTPUT CHARACTERISTICS

With the calibration data provided by the MS5534 system (stored in the interface IC) it should be possible to obtain the following characteristics:

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Resolution			0.1			mbar
Accuracy		p = 750 ... 1100mbar	-0.5		+0.5	mbar
Maximum Error over Temperature		T _a = -10...+60°C	-1		+1	mbar
Long-term Stability		6 month		2.5		mbar
Maximum Error over Supply Voltage		V _{DD} = 2.2...3.6V	-0.3	0	+ 0.3	mbar/ V

Note: The long-term stability is based on reliability measurements with products comparable to MS5534.

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 20 °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	-0.08	0	+ 0.08	°C/V

FUNCTION

◆ Pressure and temperature measurement

The main function of the MS5534 is to convert the uncompensated analog output voltage from the piezoresistive pressure sensor into a 16 Bit digital value, as well as providing a temperature-dependent voltage as 16 Bit digital value:

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

As the output voltage of a pressure sensor is strongly dependent on temperature and shows high tolerances, it is necessary to compensate for these effects. Therefore, 6 sensor-specific coefficients are stored onto the MS5534 after calibration and testing at Micronas' production facilities. These 6 sensor-specific coefficients allow an accurate software compensation in the application; this compensation procedure must be performed externally in a microcontroller.

The 6 compensation coefficients are

- Sensitivity coefficient "SENST1" (15 bit) "C1"
- Offset coefficient "OFFT1" (12 bit) "C2"
- Temperature coefficient of the sensitivity "TCS" (10 bit) "C3"
- Temperature coefficient of the offset "TCO" (10 bit) "C4"
- Reference temperature "Tref" (11 bit) "C5"
- Temperature coefficient of the temperature signal (6 bit) "C6"

The principle of the required computation is described hereafter for a four point calibration. It is written as an easy-to-use and easy-to-program routine (only with addition, subtraction and multiplication):

Basic system equations:

1. $dT (D2) = D2 - Tref$
2. $OFF (D2) = OFFT1 + TCO * dT (D2)$
3. $SENS (D2) = SENST1 + TCS * dT (D2)$
4. $PRESS (D1, D2) = (D1 * SENS (D2)) - OFF (D2)$

-> **PRESS (D1, D2)** is the calibrated pressure value in mbar

For the detailed equations, please refer to paragraph "Calculation of Pressure using Compensation Coefficients C1 to C5".

◆ Measurement principle

For both 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 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 (about 5,000 to 37,000) for all sensor variations in the specified range of temperature and pressure.

◆ Calibration

The user of MS5534 does not need to calibrate the sensor, but it might be useful to understand how the compensation coefficients stored in the module have been calculated. Following is a description of the way in which compensation coefficients are calculated during calibration and testing at Micronas' production facilities.

The module consists of a piezoresistive sensor and a sensor interface IC. The Micronas 1 bar absolute pressure sensor used in this module has tolerances in various parameters such as:

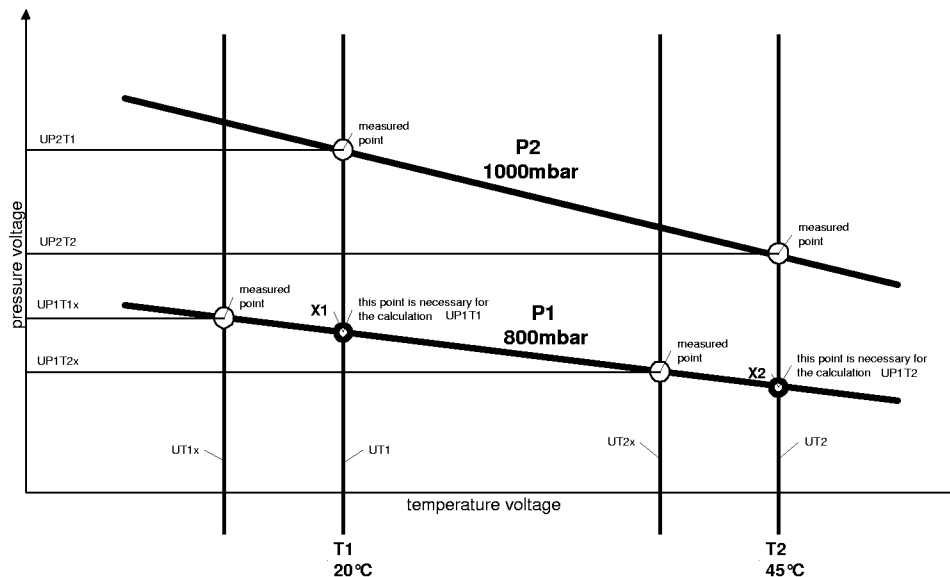
- Offset voltage varies between -8mV/V and +8mV/V
- Sensitivity varies between 24 mV/(V·bar) and 35 mV/(V·bar)
- TCO (temperature coefficient of Offset) varies between -16uV/(V·°C) and +16uV/(V·°C)
- TCS (temperature coefficient of Sensitivity) varies between -1600ppm/°C and -2200ppm/°C

Also there are small tolerances and temperature dependencies in Gain and Offset of the A/D-converter.

The module is calibrated at two temperatures $T1 = 20^\circ\text{C}$ and $T2 = 45^\circ\text{C}$, and two pressures $P1 = 800\text{mbar}$ and $P2 = 1000\text{mbar}$.

Changes in pressure result in a change in temperature and vice versa (due to physics). This means, for example, that after the first calibration at $1000\text{mbar}/20^\circ\text{C}$ a change in pressure to $800\text{mbar}/20^\circ\text{C}$ will result not only in a pressure change but change the temperature as well, and it will take considerable time to stabilise to 20°C again. Therefore the calibration algorithm had been optimised to accept tolerances in temperature from the reference.

The following graph shows a typical dependency of measured pressure value versus measured temperature for 2 different pressure values.



During calibration testing four pressure values $UP2T1$, $UP2T2$, $UP1T1x$ and $UP1T2x$ together with the equivalent temperature values $UT1$, $UT2$, $UT1x$ and $UT2x$ are measured. The "x" shall indicate that temperature differs slightly from the reference, caused by a change in pressure.

For the calculation of the sensitivity at $T1=20^\circ\text{C}$ and $T2=45^\circ\text{C}$ two imaginary points $UP1T1$ and $UP1T2$ are calculated as follows:

Calculation of $UP1T1$ and $UP1T2$

$$UP1T1 = (UP1T1x - UP1T2x) * (UT1 - UT2x) / (UT1x - UT2x) + UP1T2x$$

$$UP1T2 = (UP1T1x - UP1T2x) * (UT2 - UT2x) / (UT1x - UT2x) + UP1T2x$$

These imaginary points are used to calculate the sensitivity.

Calculation of Sensitivity and TC(Sensitivity)

$$\begin{aligned} \text{SensT1} &= (P2-P1)/(UP2T1-UP1T1) && \text{Sensitivity at T1 in mbar/PLSB} \\ \text{SensT2} &= (P2-P1)/(UP2T2-UP1T2) && \text{Sensitivity at T2 in mbar/PLSB} \\ \text{TCS} &= (\text{SensT2}-\text{SensT1})/(UT2-UT1) && \text{TC(Sensitivity) in} \\ &&& \text{mbar/PLSB/TL SB} \end{aligned}$$

Calculation of Offset and TC(Offset)

$$\begin{aligned} \text{OffT1} &= (UP1T1 - 7168)*\text{SensT1} - (P1 - 250\text{mbar}) && \text{Offset at T1 in mbar} \\ \text{OffT2} &= (UP1T2 - 7168)*\text{SensT2} - (P1 - 250\text{mbar}) && \text{Offset at T2 in mbar} \\ \text{TCO} &= (\text{OffT2}-\text{OffT1})/(UT2-UT1) && \text{TC(Offset) in mbar/TL SB} \end{aligned}$$

Example 1:

P1 = 800mbar, P2=1000mbar, T1=20°C, T2 = 45°C			
UP1T1x=22560 (20°C)	UP2T1=26155	UT1x=25927 (20°C+x)	UT1=25923
UP1T2x=21881	UP2T2=25306	UT2x=29330 (45°C+y)	UT2=29336 (45°C)
→ UP1T1=(22560-21881)*(25923-29330)/(25927-29330)+21881=22560.8 → UP1T2=(22560-21881)*(29336-29330)/(25927-29330)+21881=21879.8			
SensT1	= (1000-800)/(26155-22560.8)	= 0.0556452 mbar/PLSB	
SensT2	= (1000-800)/(25306-21879.8)	= 0.0583737 mbar/PLSB	
TCS	= (0.0583737 -0.0556452)/(29336-25923)	= 7.994*10⁻⁷ mbar/PLSB/TL SB	
OffT1	= (22560.8-7168)*0.0556452-550	= 306.535 mbar	
OffT2	= (21879.8-7168)*0.0583737-550	= 308.782 mbar	
TCO	= (308.782-306.535)/(29336-25923)	= 6.584*10⁻⁴ mbar/TL SB	

The MS5534 has 64 Bit of PROM memory that store the compensation information in the form of coefficients that are calculated out of SensT1, OffT1, TCS, TCO and UT1 as follows:

$$\begin{aligned} C1 &= (\text{SensT1} * 2^{16} - 3072) * 2^3 && 15 \text{ Bit} \\ C2 &= \text{OffT1} * 2^3 && 12 \text{ Bit} \\ C3 &= \text{TCS} * 2^{29} && 10 \text{ Bit} \\ C4 &= \text{TCO} * 2^{17} + 512 && 10 \text{ Bit} \\ C5 &= (\text{UT1}-20224) / 2^3 && 11 \text{ Bit} \\ C6 &= 10*(T2-T1)/(UT2-UT1) * 2^{10} && -50 \quad 6 \text{ Bit} \end{aligned}$$



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The calculations consist of adding offset and shift operations to obtain a maximum possible accuracy with a minimum of bits required to store the coefficients.

Example 2 (taking the highlighted values from example1):

$C1 = (0.0556452 * 2^{16} - 3072) * 2^3$	$= 4598$
$C2 = 306.535 * 2^3$	$= 2452$
$C3 = 7.994 * 10^{-7} * 2^{29}$	$= 429$
$C4 = 6.584 * 10^{-4} * 2^{17} + 512$	$= 598$
$C5 = (25923 - 20224) / 2^3$	$= 712$
$C6 = 10 * (45 - 20) / (29336 - 25923) * 2^{10} - 50$	$= 25$

For the exact location of the coefficients inside the PROM, please refer to Figure 2 in Paragraph "Serial Interface".

◆ Calculation of pressure using compensation coefficients C1 to C5

First the compensation coefficients C1 to C5 have to be read through the serial interface. This can be done one time after reset of the microcontroller that interfaces to the MS5534.

For the pressure measurement the microcontroller has to read the 15 Bit values for pressure (D1) and temperature (D2) via the serial interface in a loop (i.e. every 1 sec).

For the timing please refer to the next paragraph "Serial Interface".

The following text describes how to calculate the real pressure out of D1, D2 and C1 to C5.

1. Step -> Calculation of difference between actual temperature and calibration temperature T1

$$dUT = D2 - UT1 \quad \text{where } UT1 = 8 * C5 + 20224$$

Remark: dUT gives some indication about the temperature. It is around zero at T=20°C; the value is a positive number for higher temperatures and a negative number for lower temperatures.

2. Step -> Calculation of Offset at actual temperature

$$OFF = (C2 + (C4 - 512) * dUT / 2^{14}) * 4$$

3. Step -> Calculation of Sensitivity at actual temperature

$$SENS = C1 + C3 * dUT / 2^{10} + 24576$$

4. Step -> Calculation of the temperature compensated real pressure in mbar

$$X = SENS * (D1 - 7168) / 2^{14} - OFF$$

$$P = X * 100 / 2^5 + 250 * 100$$

$$P = X * 10 / 2^5 + 250 * 10$$

Pressure in mbar with 0.01 mbar resolution
 Pressure in mbar with 0.1 mbar resolution

◆ **Calculation of the actual temperature using compensation coefficient C6**

$$\text{TEMP} = 200 + \text{dUT} * (\text{C6}+50)/2^{10}$$

Example 3 (taking values from Example 1 and 2)

D1 = 25000, D2 = 26848, C1 = 4598, C2 = 2452, C3 = 429, C4 = 598, C5 = 712, C6 = 25			
dUT	= 26848 - (8*712 + 20224)	= 928	
OFF	= (2452 + (598-512) * 928 / 2 ¹⁴) * 4	= 9827	
SENS	= 4598 + 429*928/2 ¹⁰ + 24576	= 29563	
X	= 29563*(25000 - 7168) / 2 ¹⁴ - 9827	= 22349	
P	= 22349*100/2 ⁵ + 25000	= 94841	= 948.41 mbar
TEMP	= 200 + 928*(25+50)/2 ¹⁰	= 268	= 26.8 °C

Remark: all calculations can be handled with 16 Bit variables. Intermediate results may be 32 Bit long where only the upper 16 Bit are significant.

◆ Serial interface

The MS5534 communicates with microprocessors and other digital systems via a 3-wire serial interface as shown in Figure1. The SCLK (Serial Clock) signal initiates the data transfer and synchronises 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 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 the possible output data instructions:

- Conversion start for pressure measurement and ADC-data-out "D1" (Figure1a)
- Conversion start for temperature measurement and ADC-data-out "D2" (Figure1b)
- Calibration data read-out sequence for word 1 and word 3 (Figure1c)
- Calibration data read-out sequence for word 2 and word 4 (Figure1d)
- RESET sequence (Figure1e)

Every communication starts with a data sequence on the DIN pin to adjust the MS5534 in the chosen state. Figure1 shows in detail the whole sequences for this communication. The MS5534 works without a "Chip select" signal, and this is the reason why the DIN signal begins with a start-sequence (3 Bit high) and ends with a stop-sequence (3 Bit low). Between both sequences are the adjustment bits (4 Bit for AD-converter start and measurement choice/ 6 Bit for calibration data read out and the selection address of the four 16 Bit blocks). It is possible to interrupt the data read-out sequence with a hold of the SCLK signal after the falling edge. The maximum break time between the falling edge of DOUT for the end of conversion indication and the start of data read-out is 100ms.

The RESET-sequence sets the internal control logic into the start-up state. Before start of the conversion, it is recommended to send this RESET-sequence.

Figure2 shows the arrangement of the software calibration data in four data transmit blocks word 1 to word 4.

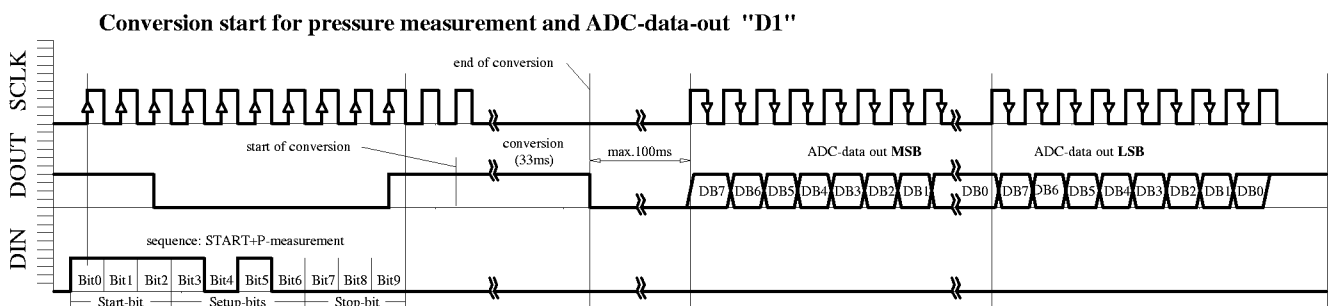


Figure1a

Conversion start for temperature measurement and ADC-data-out "D2"

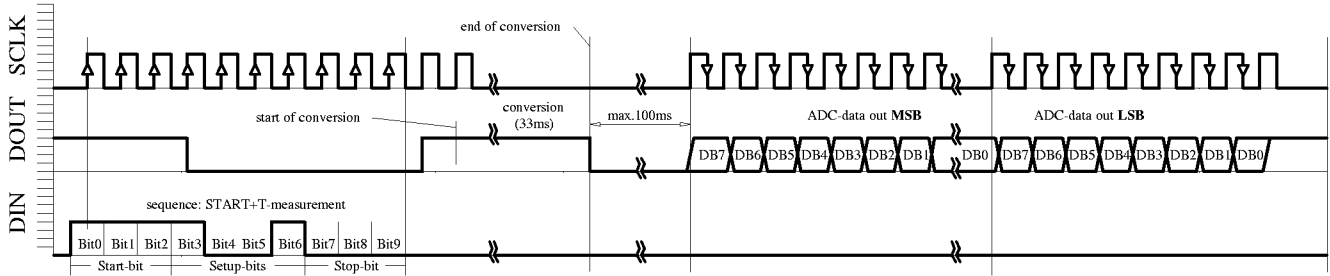


Figure1b

Calibration data read out sequence for word 1/ word 3

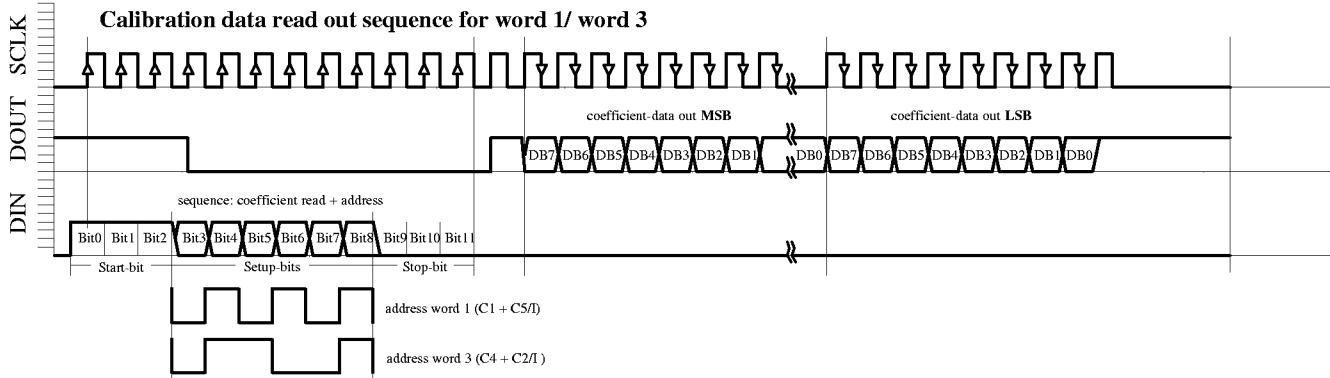


Figure1c

Calibration data read out sequence for word 2/ word 4

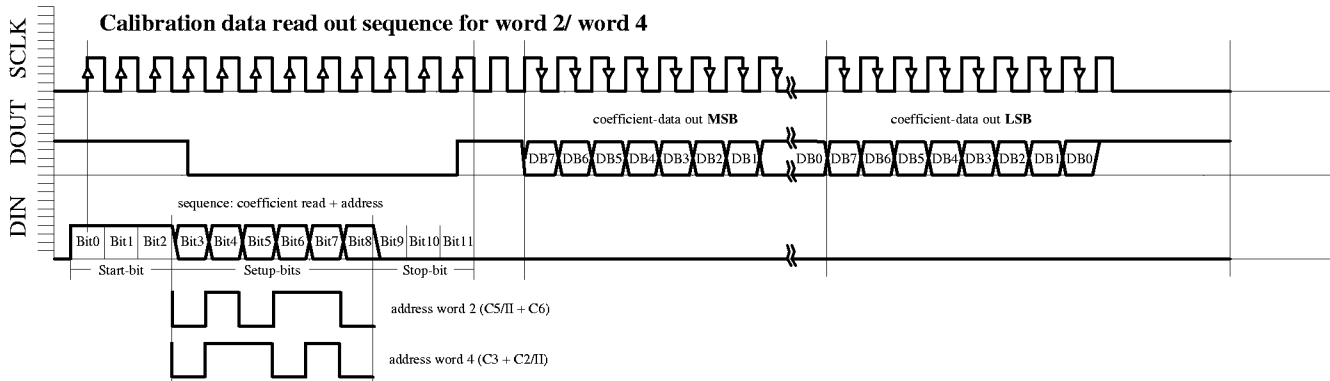


Figure1d

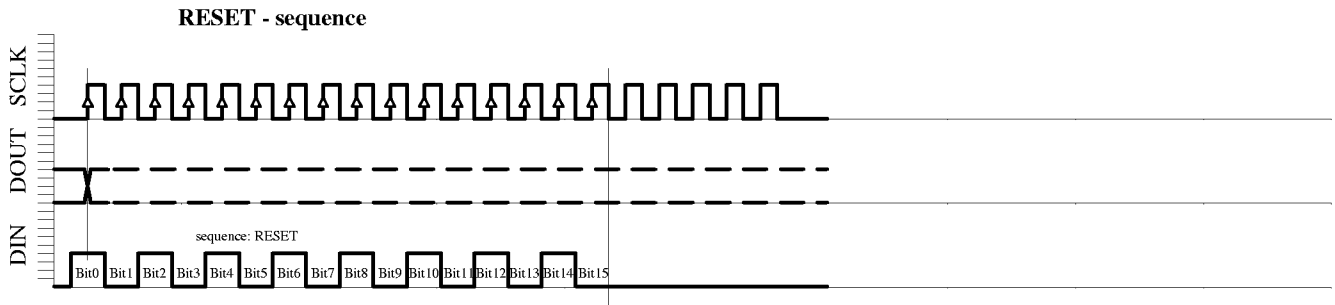


Figure1e

Arrangement of calibration data in word 1 to word 4

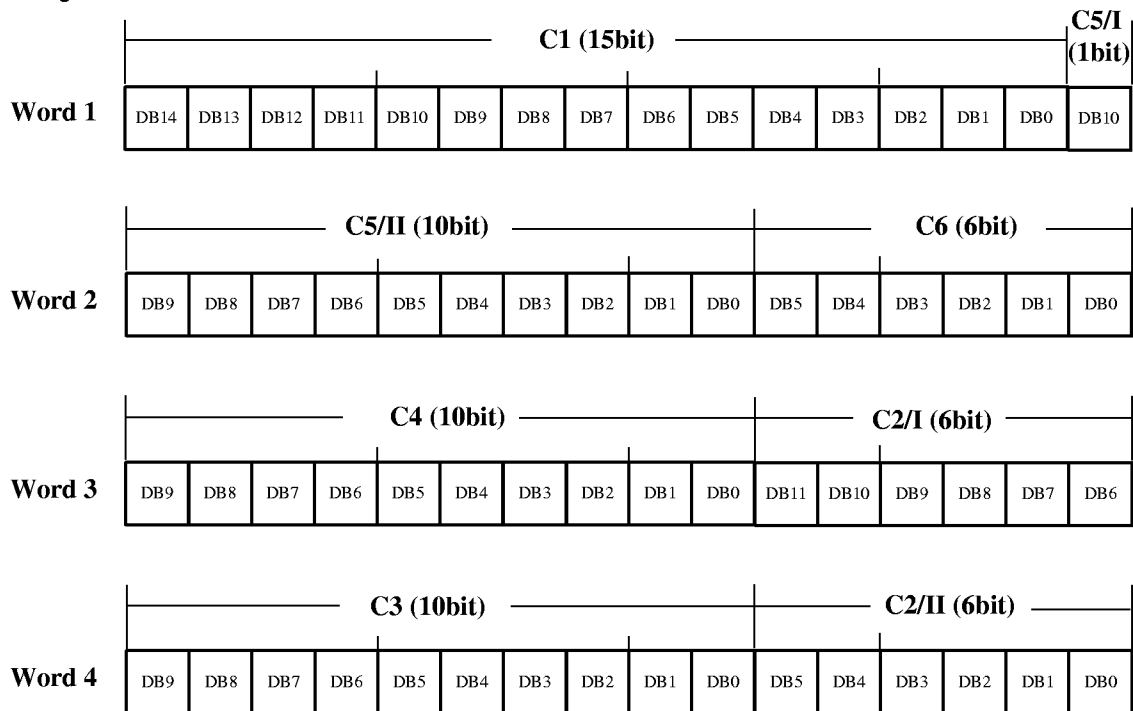


Figure 2

APPLICATION INFORMATION

• GENERAL

The idea for this combination of a sensor with a direct 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 make it also suited for industrial and automotive applications. The possibility to compensate the sensor with a software allows the user to adapt it to his particular application. Communication between the MS5534 and the widely available microcontrollers is realised over an easy-to-use 3-wire serial interface. Customers may select which microcontroller system to be used, and there are no specific standard interface cells required, which may be of interest for specially designed 4 Bit-microcontroller applications.

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.

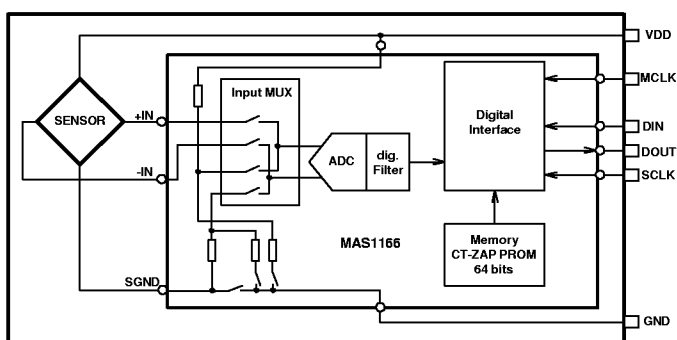
Storage of calibration data in the device will be done at module final test. Automatic test equipment is used to perform tests under pressure and temperature and to calculate individual coefficients for every sensor, which allows a highly accurate compensation.

Further, because the calibration data are stored in the MS5534, the user can save additional external memory in his microcontroller system (i.e. EEPROM).

• ALTIMETER SYSTEM USING MS5534

MS5534 is a circuit that can be used in connection with a microcontroller in mobile altimeter applications. It is designed for low-voltage systems with a supply voltage of 3V, particularly in battery applications. The MS5534 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 altimeter systems Micronas can deliver a simple formula based on a linear interpolation, where the number of interpolation points influences the accuracy of the formula.



Advantages of MS5534:

- easy layout (one side contact for flexible PCB)
- better reliability
- less 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 3: Block diagram of MS5534

• APPLICATION EXAMPLES

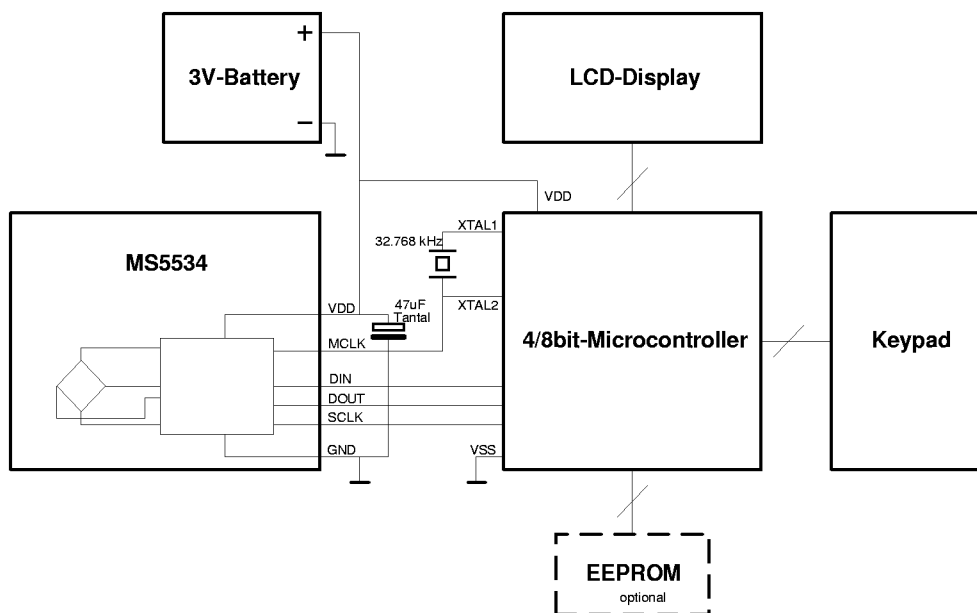
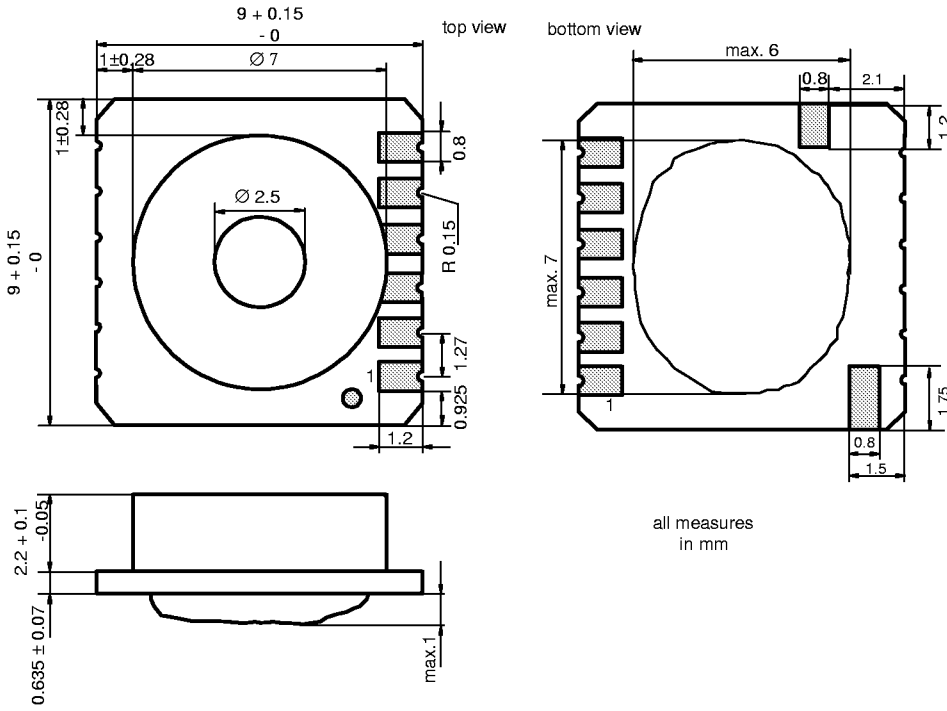


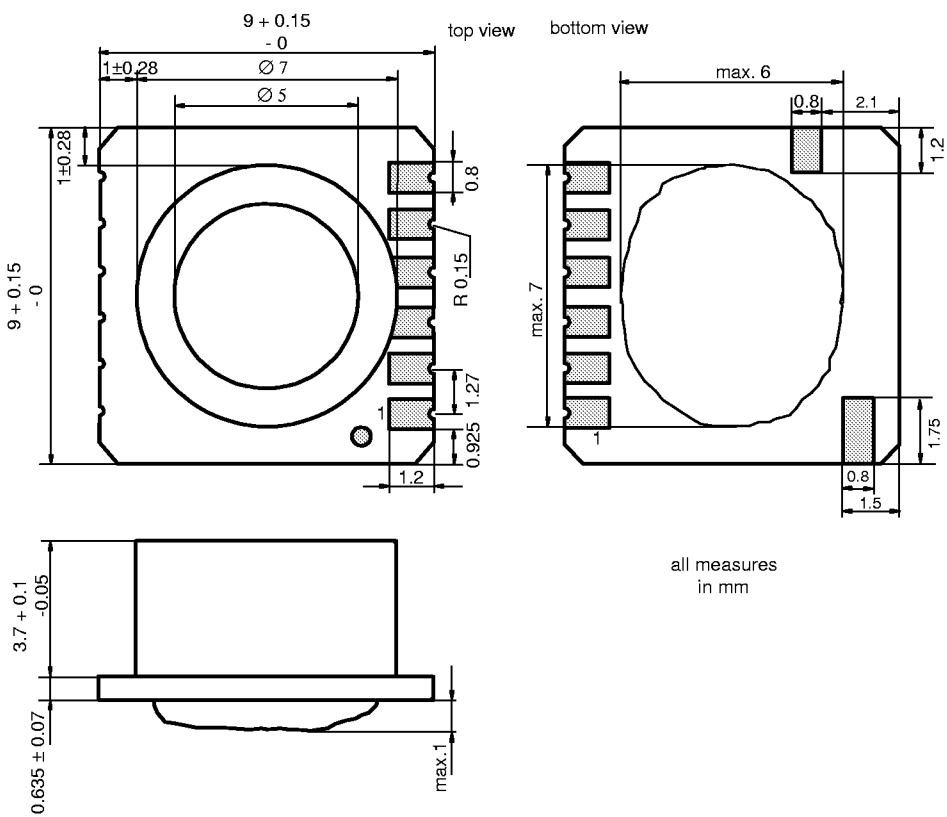
Figure 4: Demonstration of MS5534 in a mobile altimeter

DEVICE PACKAGE OUTLINES

• MS5534A



• MS5534B



ORDERING INFORMATION

Product Code	Product	Package	Comments
MS5534A	Barometer Module with plastic protection cap	SMD hybrid	standard version
MS5534B	Barometer Module with metal protection cap	SMD hybrid	

LOCAL DISTRIBUTOR

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