FEATURES

- **Board mount pressure sensor series with digital output: I²C / SPI**

- **Calibrated and temperature compensated**

- **Differential/relative, bidirectional differential, absolute and barometric sensor versions**

- **Wide variety of pressure ranges: from ultra low pressure of 1.25 mbar (125 Pa) up to 2 bar**

- **Piezoresistive sensor with high precision digital signal conditioning**

- **Total accuracy < 0.1 %FSO at room temperature for pressure ranges from 200 mbar up to 2 bar**

- **TEB < 0.25 %FSO (-25 … 85 °C) for pressure ranges from 200 mbar up to 2 bar**

- **Ultra low current consumption in sleep mode, ideal for battery powered applications**

- **Measurement speed up to 250 Hz**

- **Supply voltage: 1.7 V up to 3.6 V**

- **Digital output via I²C / SPI interface: 24 bit values for pressure and temperature**

- **Programmable I²C-address**

- **Ceramic DIP-8 package (width: 0.6 inch)**

- **Package options for tubing or manifold mount (O-Ring sealing)**

- **RoHS compliant**

TYPICAL APPLICATIONS

- Static and dynamic pressure measurement

- Gas flow measurement

- Fluid level measurement

- Medical instrumentation

- Heating, Ventilation and Air Conditioning (HVAC)

- Battery powered and mobile applications

- Vacuum monitoring

GENERAL DESCRIPTION

The digital pressure sensors in the AMS 5935 series are high-resolution 18-bit board mount sensors which provide pressure and temperature measurement data via an I²C / SPI interface. They are extensively calibrated and compensated, leading to high precision and high stability measurement data over a wide temperature range of -25 to 85 °C. With an ultra-low current consumption and a supply voltage range of 1.7 … 3.6 V, the AMS 5935 pressure sensors are especially suitable for battery-powered applications.

The AMS 5935 combine a micromachined, high quality piezoresistive pressure sensing element with a signal conditioning ASIC in a ceramic dual in-line package (DIP) for assembly on printed circuit boards (PCBs). Two package variants are available: one with vertical pressure ports for hose connection and one for O-ring sealing (N-package type for manifold mount).

Multiple pressure ranges for various pressure types are available for the sensors in the AMS 5935 series: differential (relative) pressure sensors in ranges from 0 ... 2.5 mbar up to 0 ... 1 bar, absolute pressure types from 0 ... 500 mbar up to 0 ... 2 bar and 700 ... 1200 mbar for barometric measurements. Bidirectional differential sensors are available in pressure ranges from -1.25 ... +1.25 mbar up to -1 ... +1 bar.

Custom specific pressure ranges or modifications are available on request.
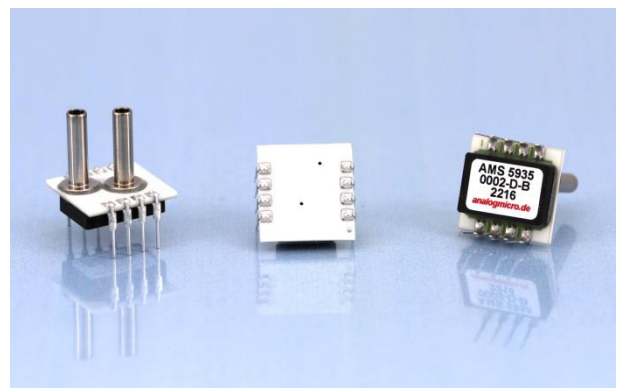
PRESSURE RANGES

Sensor types with vertical pressure ports (metal tubes for hose connection)

Sensor type (code)	Pressure type	Pressure range in mbar	Burst pressure[1] in bar	Pressure range in Pa	Burst pressure in kPa
Ultra low pressure ranges					
AMS 5935-0002-D-…	differential / relative[2]	0 … 2.5	> 0.2	0 … 250	> 20
AMS 5935-0005-D-…	differential / relative	0 … 5	> 0.2	0 ... 500	> 20
AMS 5935-0010-D-…	differential / relative	0 … 10	> 0.2	0 ... 1000	> 20
AMS 5935-0001-D-B-…	bidirectional differential	-1.25 … 1.25	> 0.2	-125 … 125	> 20
AMS 5935-0002-D-B-…	bidirectional differential	-2.5 … +2.5	> 0.2	-250 ... +250	> 20
AMS 5935-0005-D-B-…	bidirectional differential	-5 … +5	> 0.2	-500 ... +500	> 20
AMS 5935-0010-D-B-…	bidirectional differential	-10 … +10	> 0.2	-1000 ... +1000	> 20
Low pressure ranges					
AMS 5935-0020-D-…	differential / relative	0 … 20	> 0.4	0 ... 2000	> 40
AMS 5935-0035-D-…	differential / relative	0 … 35	> 0.4	0 ... 3500	> 40
AMS 5935-0050-D-…	differential / relative	0 … 50	> 1	0 ... 5000	> 100
AMS 5935-0100-D-…	differential / relative	0 … 100	> 1	0 ... 10000	> 100
AMS 5935-0020-D-B-…	bidirectional differential	-20 … +20	> 0.4	-2000 ... +2000	> 40
AMS 5935-0035-D-B-…	bidirectional differential	-35 … +35	> 0.4	-3500 ... +3500	> 40
AMS 5935-0050-D-B-…	bidirectional differential	-50 … +50	> 1	-5000 ... +5000	> 100
AMS 5935-0100-D-B-…	bidirectional differential	-100 … +100	> 1	-10000 ... 10000	> 100
Standard pressure ranges					
AMS 5935-0200-D-…	differential / relative	0 … 200	> 1.7	0 ... 20000	> 170
AMS 5935-0350-D-…	differential / relative	0 … 350	> 1.7	0 ... 35000	> 170
AMS 5935-0500-D-…	differential / relative	0 … 500	> 5	0 ... 50000	> 500
AMS 5935-1000-D-…	differential / relative	0 … 1000	> 5	0 ... 100000	> 500
AMS 5935-0200-D-B-…	bidirectional differential	-200 … +200	> 1.7	-20000 ... +20000	> 170
AMS 5935-0350-D-B-…	bidirectional differential	-350 … +350	> 5	-35000 ... +35000	> 500
AMS 5935-0500-D-B-…	bidirectional differential	-500 … +500	> 5	-50000 … +50000	> 500
AMS 5935-1000-D-B-…	bidirectional differential	-1000 … +1000	> 5	-100000 ... +100000	> 500
AMS 5935-0500-A-…	absolute	0 … 500	> 5	0 ... 50000	> 500
AMS 5935-1000-A-…	absolute	0 … 1000	> 5	0 ... 100000	> 500
AMS 5935-1500-A-…	absolute	0 … 1500	> 5	0 ... 150000	> 500
AMS 5935-2000-A-…	absolute	0 … 2000	> 5	0 ... 200000	> 500
AMS 5935-1200-B-…	absolute (barometric)	700 … 1200	> 5	70000 ... 120000	> 500

Table 1: **AMS 5935 standard pressure ranges (other pressure ranges on request)**

Notes:

1) Burst pressure is defined as the maximum pressure which may be applied to one pressure port relative to the other port (or while only one pressure port is connected) without causing leaks in the sensor.

2) Relative pressure is the difference between applied pressure and atmospheric pressure. It is often also called gage or gauge pressure.

Sensor types for manifold assembly (-N package option without tubes for O-ring sealing)

Sensor type (code)	Pressure type	Pressure range in mbar	Burst pressure[1] in bar	Pressure range in Pa	Burst pressure in kPa
Ultra low pressure ranges					
AMS 5935-0002-D-N-…	differential / relative[2]	0 … 2.5	> 0.2	0 … 250	> 20
AMS 5935-0005-D-N-…	differential / relative	0 … 5	> 0.2	0 … 500	> 20
AMS 5935-0010-D-N-…	differential / relative	0 … 10	> 0.2	0 … 1000	> 20
AMS 5935-0001-D-B-N-…	bidirectional differential	-1.25 … 1.25	> 0.2	-125 … 125	> 20
AMS 5935-0002-D-B-N-…	bidirectional differential	-2.5 ... +2.5	> 0.2	-250 ... +250	> 20
AMS 5935-0005-D-B-N-…	bidirectional differential	-5 … +5	> 0.2	-500 … +500	> 20
AMS 5935-0010-D-B-N-…	bidirectional differential	-10 … +10	> 0.2	-1000 … +1000	> 20
Low pressure ranges					
AMS 5935-0020-D-N-…	differential / relative	0 … 20	> 0.4	0 … 2000	> 40
AMS 5935-0035-D-N-…	differential / relative	0 … 35	> 0.4	0 … 3500	> 40
AMS 5935-0050-D-N-…	differential / relative	0 … 50	> 1	0 … 5000	> 100
AMS 5935-0100-D-N-…	differential / relative	0 … 100	> 1	0 … 10000	> 100
AMS 5935-0020-D-B-N-…	bidirectional differential	-20 … +20	> 0.4	-2000 … +2000	> 40
AMS 5935-0035-D-B-N-…	bidirectional differential	-35 … +35	> 0.4	-3500 … +3500	> 40
AMS 5935-0050-D-B-N-…	bidirectional differential	-50 … +50	> 1	-5000 … +5000	> 100
AMS 5935-0100-D-B-N-…	bidirectional differential	-100 … +100	> 1	-10000 … +10000	> 100
Standard pressure ranges					
AMS 5935-0200-D-N-…	differential / relative	0 … 200	> 1.7	0 ... 20000	> 170
AMS 5935-0350-D-N-…	differential / relative	0 … 350	> 1.7	0 ... 35000	> 170
AMS 5935-0500-D-N-…	differential / relative	0 … 500	> 5	0 ... 50000	> 500
AMS 5935-1000-D-N-…	differential / relative	0 … 1000	> 5	0 ... 100000	> 500
AMS 5935-0200-D-B-N-…	bidirectional differential	-200 … +200	> 1.7	-20000 ... +20000	> 170
AMS 5935-0350-D-B-N-…	bidirectional differential	-350 … +350	> 5	-35000 ... +35000	> 500
AMS 5935-0500-D-B-N-…	bidirectional differential	-500 … +500	> 5	-50000 … +50000	> 500
AMS 5935-1000-D-B-N-…	bidirectional differential	-1000 … +1000	> 5	-100000 ... +100000	> 500
AMS 5935-0500-A-N-…	absolute	0 … 500	> 5	0 ... 50000	> 500
AMS 5935-1000-A-N-…	absolute	0 … 1000	> 5	0 ... 100000	> 500
AMS 5935-1500-A-N-…	absolute	0 … 1500	> 5	0 ... 150000	> 500
AMS 5935-2000-A-N-…	absolute	0 … 2000	> 5	0 ... 200000	> 500
AMS 5935-1200-B-N-…	absolute (barometric)	700 … 1200	> 5	70000 ... 120000	> 500

Table 2: **AMS 5935 pressure ranges for manifold assembly (other ranges on request)**

Notes:

1) Burst pressure is defined as the maximum pressure which may be applied to one pressure port relative to the other port (or while only one pressure port is connected) without causing leaks in the sensor.

2) Relative pressure is the difference between applied pressure and atmospheric pressure. It is often also called gage or gauge pressure.

MAXIMUM RATINGS

Parameter	Minimum	Typical	Maximum	Units
Maximum supply voltage: $V_{S,max}$			3.6	V
Operating temperature: T_{op}	-25		85	°C
Storage temperature: T_{amb}	-40		125	°C
Common mode pressure: p_{CM}[1]			16	bar

Table 3: **Maximum ratings**

Note:

1) Common mode pressure is defined as the maximum pressure, which can be applied simultaneously on both pressure ports of a differential or bidirectional pressure sensor without causing damages, while no differential pressure is applied.

SPECIFICATIONS

All parameters apply to $T_{op} = 25$ °C and $V_S = 3.3$ V, unless otherwise stated.

Parameter	Minimum	Typical	Maximum	Units
Digital output signal (pressure)[1]				
@ specified minimum pressure (see "pressure range")[2]		$0.1 \cdot 2^{24}$		counts
@ specified maximum pressure (see "pressure range")[2]		$0.9 \cdot 2^{24}$		counts
Full span output (FSO)[3]		$0.8 \cdot 2^{24}$		counts
without pressure (bidirectional differential)		$0.5 \cdot 2^{24}$		counts
Digital output signal (temperature)[4]				
@ minimum temperature $T = -25$ °C		$0.\overline{09} \cdot 2^{24}$		counts
@ maximum temperature $T = 85$ °C		$0.\overline{75} \cdot 2^{24}$		counts
Total accuracy[5] **(pressure measurement) @ $T = 25$ °C**				
Pressure ranges: ±1.25 mbar, 0 … 2.5 mbar			± 0.6	%FSO
Pressure ranges: ±2.5 mbar, 0 … 5 mbar			± 0.5	%FSO
Pressure ranges: ±5 mbar up to ±100 mbar			± 0.3	%FSO
Pressure ranges: 0 … 10 mbar up to 0 … 100 mbar			± 0.3	%FSO
Pressure ranges: 0 … 200 mbar up to 0 … 2 bar			± 0.1	%FSO
TEB/Overall error[6] **(pressure meas.) @ $T = -25 ... 85$ °C**				
Pressure ranges: ±1.25 mbar, 0 … 2.5 mbar			± 1.5	%FSO
Pressure ranges: ±2.5 mbar, 0 … 5 mbar			± 1.0	%FSO
Pressure ranges: ±5 mbar up to ±100 mbar			± 0.5	%FSO
Pressure ranges: 0 … 10 mbar up to 0 … 100 mbar			± 0.5	%FSO
Pressure ranges: 0 … 200 mbar up to 0 … 2 bar			± 0.25	%FSO
Total error for temperature measurement				
All types of AMS 5935 $T = -25 ... 85$ °C			± 1.5	%FSO
Long term stability			< 0.5	%FSO/a
Supply voltage range (V_S)	1.7	3.3	3.6	V

| Parameter	Minimum	Typical	Maximum	Units
Resolution A/D converter		18		bits
Resolution pressure signal[7]	17		18	bits
Resolution temperature signal			16	bits
Current consumption (in sleep mode)			250	nA
Current consumption (in active mode)			2	mA
Time in active mode / single measurement time with $0xAA_{Hex}$		4.0		ms
Time in active mode / 4x oversampling meas. time with $0xAD_{Hex}$		14.5		ms
Start-up time (V_S ramp up to ready for first measurement)		2.5		ms
Maximum measurement speed (using $0xAA_{Hex}$)		250		Hz
I²C-interface				
Input high level	80		100	% V_S
Input low level	0		20	% V_S
Output low level	0		20	% V_S
Load capacitance @ SDA			100	pF
Clock frequency SCL		100	400	kHz
Pull-up resistor	1		20	kΩ
Pressure changes	10^6			
Compensated temperature range	-25		85	°C
Weight		3		g
Media compatibility	See "Specification notes"[8), 9)]			

Table 4: **Specifications**

SPECIFICATION NOTES

1) The digital pressure output signal is <u>not</u> ratiometric to the supply voltage.

2) The pressure ranges with specified minimum and maximum pressure are listed in *Table 1* and *Table 2*.

3) The Full Span Output (FSO) is the algebraic difference between the output signal at the specified maximum pressure and the output signal at the specified minimum pressure (see *Table 1* and *Table 2*).

4) The digital temperature output signal is <u>not</u> ratiometric to the supply voltage. The temperature output value is the overall sensor temperature. It is measured at the sensor's signal conditioning ASIC and is influenced by the measurement media's temperature, the ambient temperature, the sensor's self-heating and the thermal conductivity of the material in contact to the sensor (e.g. PCB, mounting assembly, pressure hoses).

5) Total accuracy is defined as the maximum deviation of the measurement value from the ideal characteristic curve at room temperature (RT) in %FSO including the adjustment errors (offset and span), nonlinearity, pressure hysteresis and repeatability. Nonlinearity is the measured deviation from the best fit straight line (BFSL) across the entire pressure range. Pressure hysteresis is the maximum deviation of the output value at any pressure within the specified range when the pressure is cycled to and from the minimum or maximum rated pressure. Repeatability is the maximum deviation of the output value at any pressure within the specified range after 10 pressure cycles.

6) The TEB (total error band or overall error) is defined as the maximum deviation of the measurement value from the ideal characteristic curve in %FSO across the entire temperature range (-25 ... 85 °C).

7) For the pressure ranges 0 … 2.5 mbar and -1.25 … +1.25 mbar, the minimum resolution is 16 bit.

8) Media compatibility of pressure port 1 (for a description of port 1 see *Figure 9* and *Figure 10*): clean, dry gases, non-corrosive to silicon, RTV silicone rubber, epoxy, gold (alkaline or acidic liquids can destroy the sensor). For standard packages with tubes, the media compatibility of the nickel-plated steel tubes has to be considered, too.

9) Media compatibility of pressure port 2 (for a description of port 2 see *Figure 9* and *Figure 10*): fluids and gases non-corrosive to silicon, Pyrex, RTV silicone rubber. For standard packages with tubes, the media compatibility of the nickel-plated steel tubes and its epoxy adhesive has to be considered, too.

FUNCTIONAL DESCRIPTION

The pressure sensors in the AMS 5935 series combine a high quality, membrane-based piezoresistive silicon sensing element with a modern mixed-signal CMOS ASIC for signal-conditioning in a ceramic package. This enables a low total error band, excellent temperature behavior and long-term stability.

AMS 5935's functional principle is explained using *Figure 1*.
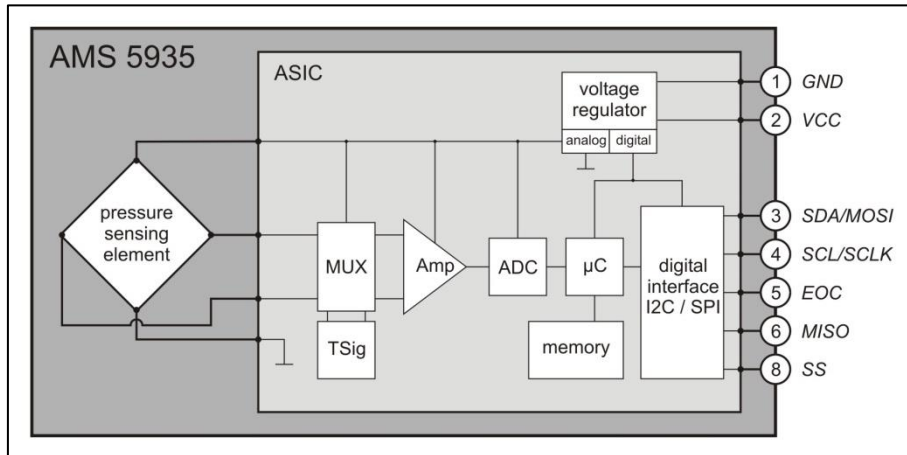
Figure 1: **Functional principle**

The physical pressure applied to AMS 5935's pressure port(s) is converted into a differential voltage signal at AMS 5935's piezoresistive pressure sensing element. This differential voltage is signal-conditioned and converted into a standardized digital output signal in the following way:

At first, the sensing element's differential voltage signal is transmitted through the multiplexer and amplifier block to the A/D converter block (ADC), where it is converted into a digital signal with 18 bit resolution. This digitized signal is then mathematically processed by the ASIC's integrated microcontroller unit (µC) to obtain a calibrated and temperature compensated output signal. For this purpose, the µC uses a correction algorithm and individual correction coefficients that are stored in the ASIC's memory during AMS 5935's factory calibration. This enables sensor-specific calibration and correction (i.e. linearization and temperature compensation) of the digitized pressure signal. The temperature signal, which is required for temperature compensation, is generated in the ASIC's temperature reference block and transmitted via the multiplexer to the amplifier and then to the ADC, where it is digitized, too. Using its correction algorithm, the microcontroller calculates the current corrected and standardized pressure and temperature measurement data (24 bit pressure value and 24 bit temperature value), which are written to the ASIC's output register. The readout of the standardized digital output values for pressure and temperature from the output registers can be done via the sensor's digital I^{2}C / SPI interface. For I²C communication, PIN3 (SDA) and PIN4 (SCL) are used and PIN3 (MOSI), PIN4 (SCLK), PIN6 (MISO) and PIN8 (SS) for SPI communication. AMS 5935's digital output values (for pressure and temperature) are not ratiometric to the supply voltage.

AMS 5935's functional blocks are powered by a stabilized voltage supply, which is divided into two parts. The digital part supplies the microcontroller, memory and digital interface and the analog part powers the sensing element, MUX, amplifier and ADC.

To reduce the sensor's current consumption, the sensor features a sleep mode. After powering up, it immediately enters sleep mode, wherein only the ASIC's digital part is powered and waits for a command on the I^{2}C/SPI interface. To obtain measurement data from AMS 5935, a measurement request has to be sent on the digital interface. Upon reception of the measurement request, the ASIC enters active mode, the sensor's analog part is powered up and the measurement cycle is started. Depending on the used command, the sensor either performs a single measurement or four measurements from which it calculates the mean value. After completion of the measurement cycle (duration: 4.0 ms for single measurement, 14.5 ms for four-fold measurement), the corrected pressure and temperature data are stored in the output register and the ASIC returns to sleep mode. The standardized digital 24 bit output values for pressure and temperature can be read from the sensor's digital interface via I^{2}C/SPI, without waking the sensor from sleep mode.

INITIAL OPERATION

Electrical connection

The electrical connection of AMS 5935 sensors is typically established by soldering them directly on a printed circuit board or by mounting them on a suitable socket.

Depending on whether the I^{2}C or SPI protocol should be used for data readout, different pins have to be connected.

For data readout using I^{2}C, the basic circuit for the AMS 5935 sensor is shown in *Figure 2.* It is sufficient to connect PIN1 (GND), PIN2 (VCC) and the I^{2}C-bus lines to PIN3 (SDA) and PIN4 (SCL).

Important: Each bus line (SDA and SCL) has to be connected to the positive supply voltage (pin Vcc with $V_{S,typ}$ = 3.3 V) via a pull-up resistor. Please add pull-up resistors (10 kΩ are recommended) to your bus line if they are not integrated in the I^{2}C -master.
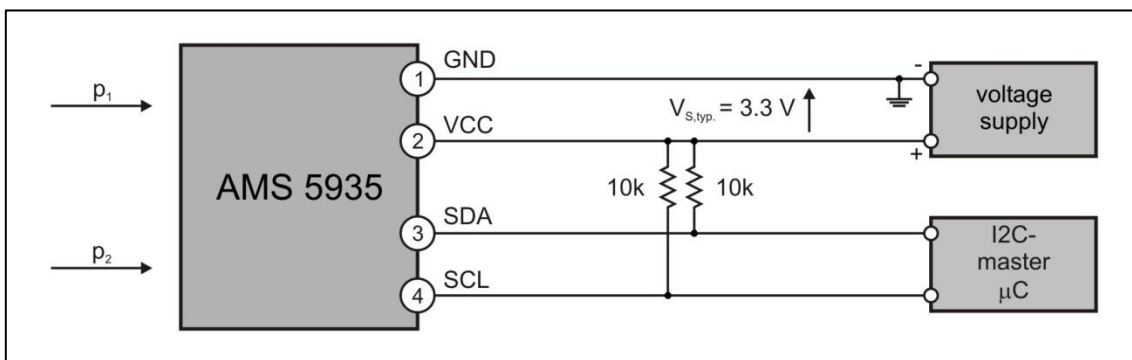
Figure 2: **Principle electric circuitry for I2C communication**

In order to read out the data using SPI, the basic circuit for the AMS 5935 sensor is shown in *Figure 3.* For SPI communication, PIN1 (GND), PIN2 (VCC) and the SPI-bus lines at PIN3 (MOSI), PIN4 (SCLK), PIN6 (MISO) and PIN8 (SS) have to be connected.
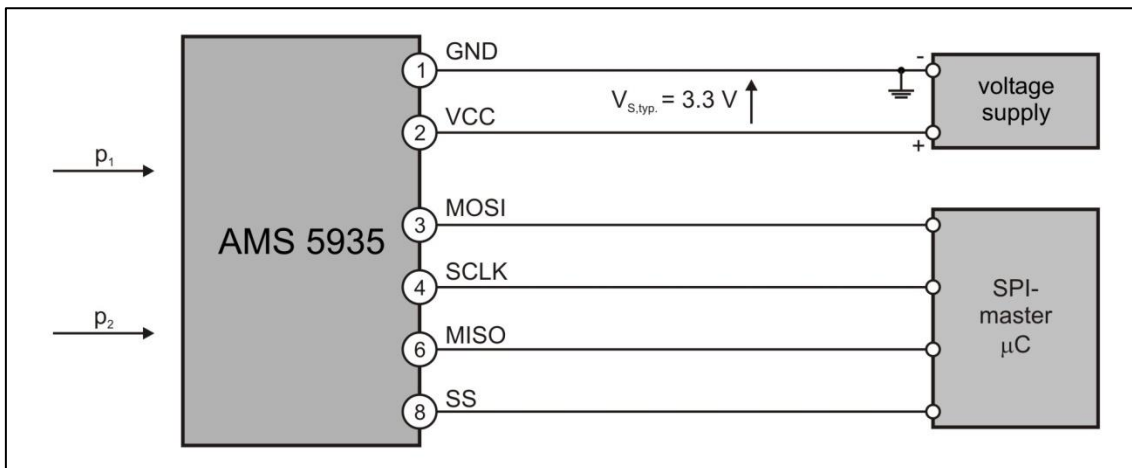
Figure 3: **Principle electric circuitry for SPI communication**

Regardless of the communication protocol used, PIN5 (EOC) can additionally be connected to a microcontroller and used to determine whether a started measurement cycle has been completed and the measurement data are ready for readout. It is on low level (logic 0) during the measurement cycle and turns to high level (logic 1) as soon as the measurement data can be read from the output register.

Pressure connection

The pressure connection is established by mounting hoses / flexible tubing on the sensor's metal pressure ports or by sealing the pressure ports of the N-type package via O-rings to a suitable flange. Depending on the sensor type and the type of measuring pressure, one or two of the pressure ports have to be connected to the measuring medium / volume, as described in the table below:

Sensor type	Pressure type to measure	Port 1	Port 2	Requirement
AMS 5935-xxxx-D	differential	connected to p_1	connected to p_2	$p_1 \leq p_2$
	positive gage	open	connected to p_2	$p_2 \geq p_{ambient}$
	negative gage (vacuum)	connected to p_1	open	$p_1 \leq p_{ambient}$
AMS 5935-xxxx-D-B	differential (bidirectional)	connected to p_1	connected to p_2	$p_1 \geq p_2$ or $p_1 \leq p_2$
AMS 5935-xxxx-A	absolute pressure	connected to p_1	not connected	p_1 = meas. pressure
AMS 5935-xxxx-B	barometric pressure	connected to p_1	not connected	p_1 = meas. pressure

wherein p_1 = pressure at port 1 and p_2 = pressure at port 2. For port declaration see *Figure 9* and *Figure 10*. The media compatibility of pressure ports 1 and 2 can be found in "Specification notes", 7 and 8.

Notes:

1) For pressure connections up to 2 bar we recommend a silicone tubing (inner diameter Ø = 2 mm, outer diameter Ø = 6 mm) and above 2 bar PU or PA tubing. Suitable tubing can be found on AMS 5935's product page.

2) Except for pin 7 unused pins have to be left unconnected. Pin 7 is internally not connected.

3) ESD precautions are necessary. It is essential to ground machines and personnel properly during assembly and handling of the device.

I2C COMMUNICATION WITH AMS 5935

The AMS 5935's digital interface supports communication via an I^2C bus with the electrical connection as depicted in *Figure 2*. To configure AMS 5935's digital I2C/SPI interface for I2C communication, the first command after a power on has to be a valid I2C command. This configuration has to be renewed after each power on or after a power-on-reset (POR).

The I2C communication protocol is based on a simple master-slave principle, where the AMS 5935 operates as slave. The master can be a microcontroller, computer or a starter kit for example. Data transfer is always initialized by the master, who starts and ends the communication and generates the signal on the serial clock line which synchronizes the communication between master and sensor.

Basics of I^2C communication

Communication via I²C requires two bus lines: a serial data line (SDA) and a serial clock line (SCL). The SDA and SCL lines have to be connected to the positive supply voltage using pull-up resistors. The SDA line is a bidirectional data line used to transfer data in both directions between the I2C master and sensor. The SCL line is the serial clock line.

Data transfer is always initialized by the I2C master, which sends the sensor's 7-bit address followed by the data direction bit. If the data direction bit is "1" (write = W) the sensor receives the controller's command and processes it. If the data direction bit is "0" (read = R), the sensor answers with the data in its output register.

AMS 5935's I^{2}C communication adheres to the standard I²C communication protocol (shown in *Figure 4*) with the following communication phases:

Idle period (bus is free)

When the bus is free, both I²C-bus lines (SDA and SCL) are pulled up to supply voltage level.

Start S (start condition)

Prior to any data transfer on the bus, a start condition has to be generated. The start condition is always sent by the I2C master. The start condition is defined as a transition from high-level voltage to low-level voltage on the SDA line, while the SCL line is still on high-level voltage.

Stop P (stop condition)

The stop condition is always generated by the I²C master after a data transfer has been completed. The stop condition is defined as a transition from low-level voltage to high-level voltage on the SDA line while the SCL line is still on high-level voltage. The I^{2}C communication with AMS 5935 is always terminated by a stop condition.

Valid data

Data is transmitted in bytes = 8 bit, starting with the most significant bit. Each data bit is transmitted with the related clock pulse generated by the I2C master. The transmitted bits are only valid if, following a start condition, the level on the SDA line is constant as long as the SCL line is on high-level voltage. Changes to the SDA level must be made while the SCL line is on low-level voltage.

Acknowledge A / Not Acknowledge N

After a byte has been transmitted, the respective receiver (I2C master or sensor) has to send an acknowledge (additional acknowledge bit) confirming the correct receipt of the data. For this purpose, the I2C master generates an extra acknowledge-related clock pulse. The receiver sends the acknowledge bit by pulling the SDA line down to low-level voltage during the additional clock pulse. If the receiver pulls the SDA line up to high-level voltage during the acknowledge-related clock pulse, it is interpreted as not acknowledge and the communication between I2C master and sensor is stopped.

Addressing (I²C-address AMS 5935)

After the start condition, the I2C master sends an addressing byte to initiate the communication with a specific sensor. The addressing byte contains the individual 7-bit address of the selected AMS 5935 and a data direction bit (R/$\overline{\text{W}}$). A "0" for the data direction bit indicates a transmission from I2C master to sensor (the I2C master wishes to transmit data to the selected sensor) or a "1" indicates a data request from the I2C master (the I2C master wants to read data from the sensor).

The pressure sensors in the AMS 5935 series have a factory-programmed 7-bit address of $0x28_{Hex}$ (0101000_{bin}), which is stored in the sensor's memory.

On request, each AMS 5935 can be ordered with an individual 7-bit address programmed at the factory. Using AMS 5935's USB starter kit, the customer can program the individual address himself.

In general, 7-bit addressing allows 128 different addresses. If more than one AMS 5935 are connected to the same I^{2}C -bus, each pressure sensor requires an individual I^{2}C address. Since the addresses $0x04_{Hex}$ to $0x07_{Hex}$ are internally used by AMS 5935, they cannot be used as I^{2}C address. Thus, 124 addresses remain for the user's purpose.

Notes:

There are three differences between AMS 5935's communication protocol and the original I²C communication protocol:
1) A stop condition directly after a start condition without clock pulses in between is not allowed. This creates a communication error for the next communication.
2) A second start condition (restart) during data transmission when SCL is still high is not allowed.
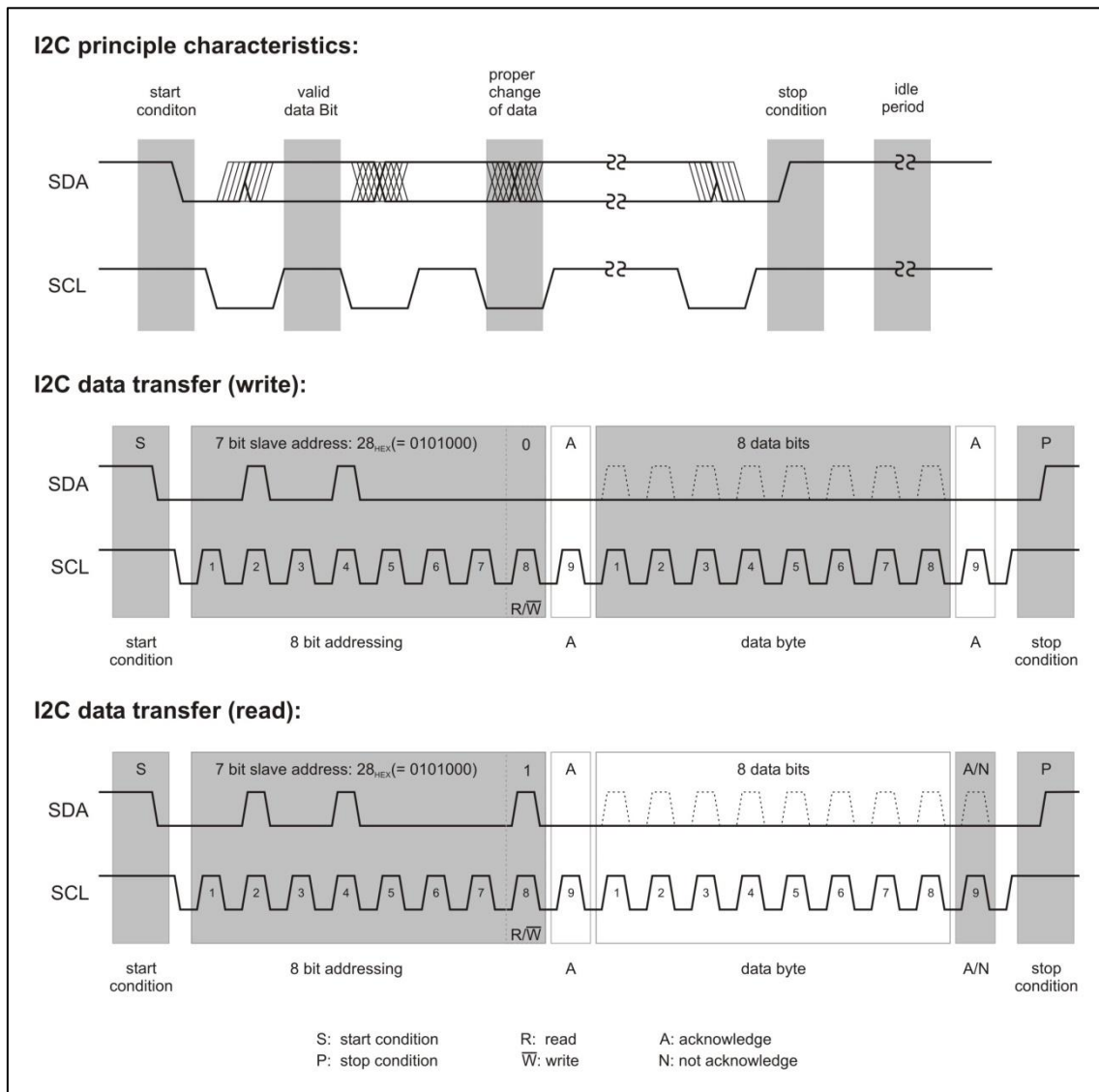3) Between the start condition and the first rising SCL edge, a falling SDA edge is not allowed.

I2C principle characteristics:

I2C data transfer (write):

I2C data transfer (read):

S: start condition   R: read   A: acknowledge
P: stop condition $\overline{W}$: write   N: not acknowledge

Figure 4: **Standard I²C protocol**

### Data readout from AMS 5935 via I²C

By default, AMS 5935 is in sleep mode after powering up. To wake up the sensor from sleep mode and to start a measurement, an I2C data request command has to be sent from the master to the sensor. After the measurement has been processed (4.0 ms for single measurement, 14.5 ms for four-fold measurement), the I²C master (controller) can read the data from the sensor's output register by sending a data readout command.

Start measurement command (I²C data request)

To start the measurement cycle, the controller has to send a data request command: $0xAA_{Hex}$ for single measurement or $0xAD_{Hex}$ for four-fold oversampling. This is described using *Figure* 5.

For this purpose, the controller generates a start condition on the I²C-bus lines at first. Following the start condition, the controller sends the addressing byte containing the 7-bit address of the AMS 5935 (programmed to $0x28_{Hex} = 0101000_{bin}$ at the factory) and the data direction bit (W = "1"). The selected pressure sensor answers to the addressing byte with an acknowledge bit during the acknowledge-related clock pulse. Afterwards, the controller sends the data request command $0xAA_{Hex}$ or $0xAD_{Hex}$.
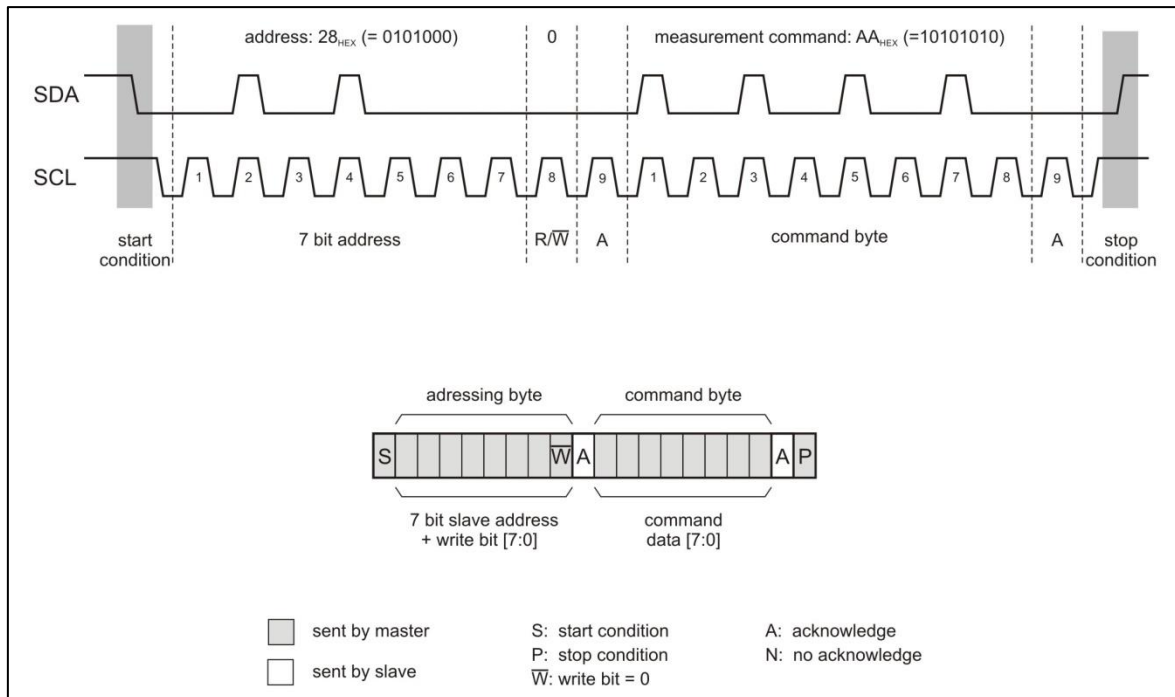
Figure 5: **Starting a single measurement (I^{2}C data request with command 0xAA$_{Hex}$)**

Upon receiving the command 0xAA$_{HEX}$, the sensor executes a single pressure and temperature measurement and stores the measurement values in the output buffer.

If the controller sends 0xAD$_{Hex}$ instead of AA$_{HEX}$, the sensor executes an oversampling measurement. Four pressure and temperature measurements are executed and the mean values are stored in the output buffer. There is no power down between the four measurements. The 0xAD$_{Hex}$ command is recommended, if low-noise signals are important for your application.

After the respective data request command has been sent, the AMS 5935 answers with an acknowledge bit indicating that the command has been understood.

The data request is finished with a stop condition sent by the I^{2}C controller.

Read measurement command (I^{2}C read)

After 4.0 ms for a single measurement or 14.5 ms for a four-fold oversampling measurement, the measurement cycle is finished and data can be read from the sensor's output register (see *Figure 6*).

To initiate the data readout, the I^{2}C controller generates a start condition and sends the sensor's 7-bit I^{2}C address followed by the data direction bit (R = "1"). Again, the sensor answers with an acknowledge bit during the acknowledge-related clock pulse and starts to send the data stored in its output register to the controller.

For a complete pressure and temperature measurement, 7 bytes are sent. The first byte contains the sensor's status, the next three bytes the sensor's 24-bit digital pressure measurement value, and the last three bytes the 24-bit digital temperature measurement value. The measurement data always start with the most significant byte and each byte begins with the most significant bit. On each transferred data byte, the controller sends an acknowledge bit, which confirms the correct receipt of the data. After the seventh byte, the controller stops the readout by sending a not-acknowledge bit and a stop condition.

If less than the full seven data bytes are required, the controller can stop the data transfer after every complete byte by sending a not-acknowledge bit and a stop condition. For example, this allows to read the status byte only (stop after 1 byte) or to stop the readout after the pressure measurement data (stop after four bytes).
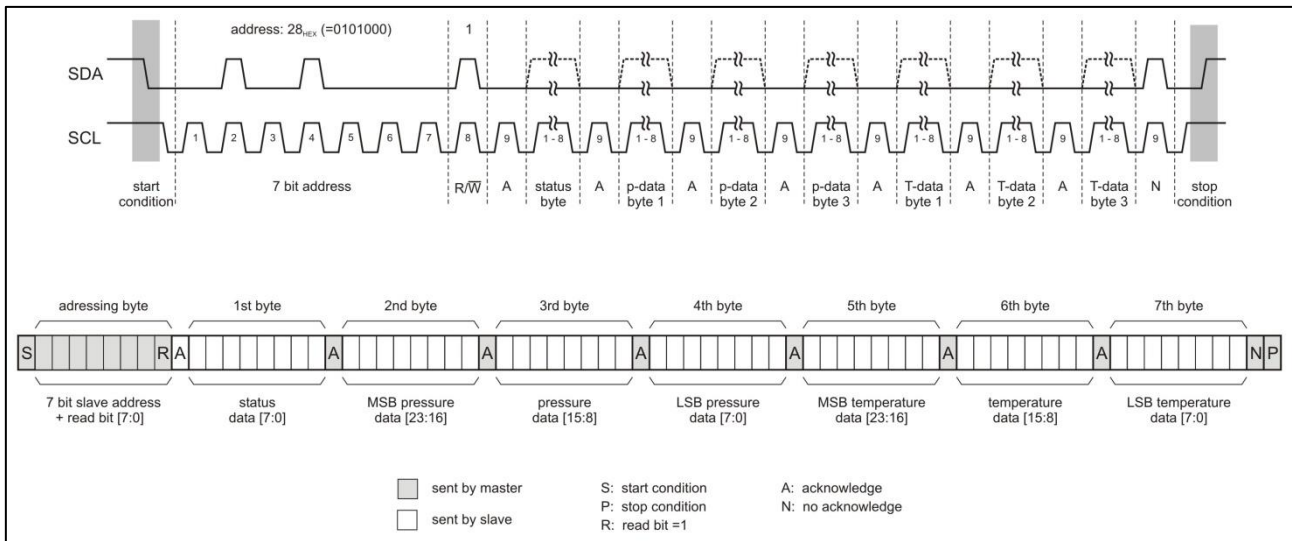
Figure 6: I²C data readout of the full measurement data of 7 bytes
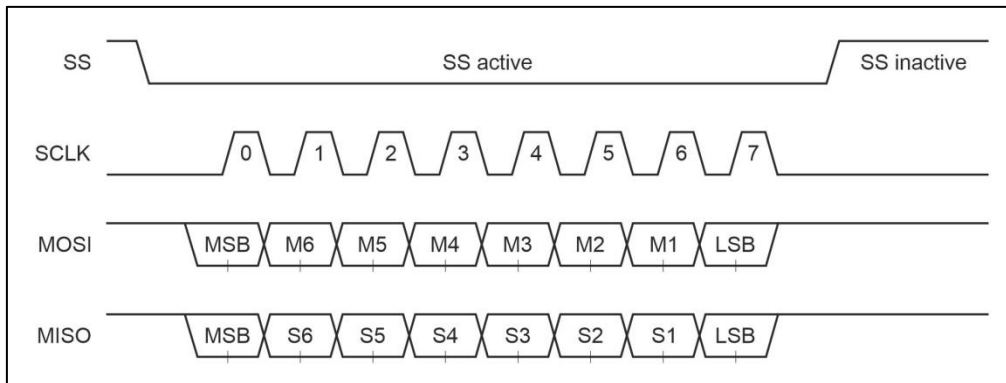
SPI COMMUNICATION WITH AMS 5935

AMS 5935's digital interface supports communication via an SPI bus, using the electrical connection illustrated in *Figure 3*. To configure AMS 5935's digital I2C/SPI interface for SPI communication, the first interaction after a power on has to be the activation of the SS line. During the start-up process (2.5 ms after power on) no transition on the SCKL line is allowed. The SPI configuration of AMS 5935's digital interface has to be renewed after each power on or after a power-on-reset (POR).

The SPI communication protocol is based on a simple master-slave principle, where the AMS 5935 always operates as slave. The master can be a microcontroller, computer or a starter kit for example. Data transfer is always initialized by the SPI master, who starts and ends the communication and generates the signal on the serial clock line which synchronizes the communication between SPI master and sensor.

Basics of SPI communication

Communication via SPI bus requires four bus lines: SS (slave select), SCKL (serial clock), MOSI (master output slave input) and MISO (master input slave output). The SS line is used to select the slave for communication. The SCKL line synchronizes the data transfer, which is done via the data lines MOSI and MISO. The data bus lines MOSI and MISO are unidirectional. Data from the SPI master to the slave is only transmitted via the MOSI line. Conversely, data from the slave to the SPI master is only transmitted via the MISO line. The data transfer is always started by setting the SS line active and stopped by deactivating it.

The SPI protocol offers a number of adjustable settings, concerning the polarity of the SS line (SS_polarity), the polarity of the SCKL line (CPOL) and the timing of data read (CPHA). The following description gives an introduction of the SPI communication based on the SPI configuration: SS_polarity = "0" (SS line is low in active state), CPOL = "0" (SCKL is low in idle state), and CPHA = "0" (data read at rising edge of SCKL line), which is the standard configuration for AMS 5935.

Figure 7: **SPI protocol with AMS 5935's SPI configuration (CPOL = 0, CPHA = 0, SS_pol = 0)**

AMS 5935's SPI communication adheres to the communication protocol shown in *Figure 7* with the following communication phases:

Idle period (bus is free)

When the bus is free, the SS line is inactive and pulled to high level voltage, the SCKL line is pulled to low level voltage.

Start S (activate SS line)

The controller initiates the communication by pulling the SS line from high level to low level voltage, which is the active state.

Stop P (deactivate SS line)

To end the communication, the controller sets the SS line back to the inactive state (high level voltage).

Data transfer

Data are transmitted in bytes (1 byte = 8 bit) on MOSI and MISO line, starting with the most significant bit. Each data bit is transmitted with a related clock pulse on SCKL. Data are set at the falling edge and read at the rising edge of each clock pulse on SCKL. The transmitted bits are valid if the voltage level on MOSI, respectively MISO, does not change during the clock edge for data read out.

Multiple slaves on the same SPI bus

If multiple slaves have to be connected on the same SPI bus, all slaves share the SCKL, MOSI and MISO lines in parallel. Each slave needs to have his own SS line to the SPI master.

Customized SPI settings

On demand, the sensor can be set to customized SPI settings concerning SS_polartiy, CPOL and CPHA. For further information, please contact info@analogmicro.de.

Data readout from AMS 5935 via SPI

After power on, the AMS 5935 is coming up in sleep mode. To wake the sensor from sleep mode and start a measurement, the SPI data request command has to be sent to the sensor by the master/controller. After the measurement has been processed (4.0 ms for single measurement, 14.5 ms for four-fold measurement) the controller can read the data from the sensor's output using the SPI data read command. The data readout is illustrated in *Figure 8*.

SPI data measurement command

To start a single measurement cycle, the controller activates the SS line and sends the data request command 0xAA 00 00$_{Hex}$ via the MOSI line to AMS 5935 as depicted in the upper part of *Figure 8*. At the same time the sensor responds with three bytes starting with the status byte followed by two invalid data bytes on the MISO line. After the transfer of the data request command is fully completed, the SS line is set inactive.[1] In the following 4 ms the sensor performs the measurement and provides the current measurement values for pressure and temperature at the output register of AMS 5935.

If instead of 0xAA 00 00$_{Hex}$ the command 0xAD 00 00$_{Hex}$ is sent by the controller, the sensor performs a fourfold oversampling measurement, as illustrated in the lower part of *Figure 8*. In the following 14.5 ms the sensor performs four measurement cycles and calculates the mean values, which are written to the output register of AMS 5935. There is no power down between the four measurements. The 0xAD 00 00$_{Hex}$ command is recommended if low-noise signals are important for your application.
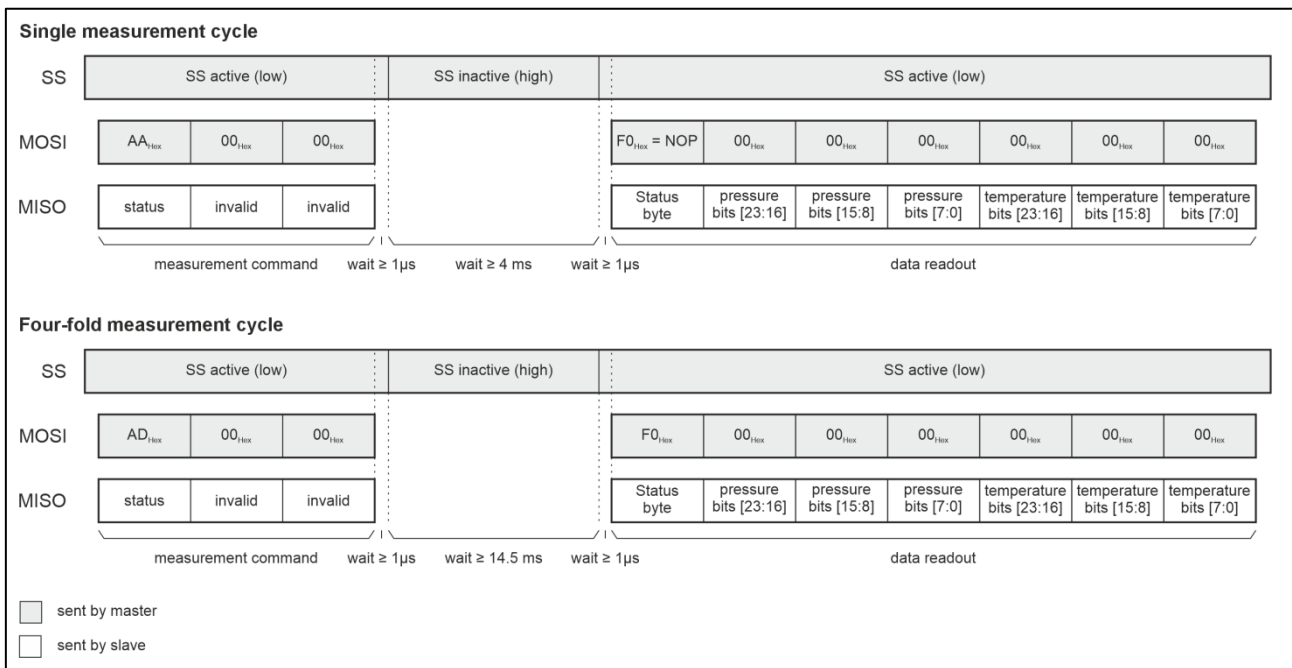
Figure 8: SPI Data Readout

SPI data read command

After finishing the measurement process the data can be read from the AMS 5935's output registers as shown in *Figure 8*. To initiate the data readout, the controller sets the SS line active and sends the full measurement command: 0xF0 00 00 00 00 00 00$_{Hex}$ to AMS 5935 on the MOSI line. Simultaneously, the sensor sends 7 bytes of data on the MISO line. The first byte contains the sensor's status, the next three bytes the sensor's 24-bit digital pressure measurement value and the last three bytes the 24-bit digital temperature measurement value. The measurement values are transmitted with the most significant byte first. At the end of the data readout, the controller sets the SS line inactive.

If only the pressure measurement value is required, the controller sends the command 0xF0 00 00 00$_{Hex}$ instead of the full measurement command. Simultaneously, the sensor answers with the status byte and the three pressure measurement bytes.

Additionally, the status byte can be read without performing a measurement command. In this case, the master sets the SS line active and sends the command 0xF0$_{HEX}$ over MOSI line. The sensor answers simultaneously with the status byte. The master ends the communication by setting the SS line inactive.

---

[1] A short wait time (1µs) between sending the command via MOSI and setting the SS line to inactivity can be necessary to guarantee a successful data transfer.

DATA INTERPRETATION

Status byte

The first byte is the status byte and contains essential information about the AMS 5935's state. It is always sent as the first data byte in a data read process and contains the following information, also shown in *Table 5:*

Status bit [7:6]: always [0:1]

Status bit 5 / busy: As long as the sensor performs the measurement cycle, this bit is "1". The bit is set to "0" if the sensor data is ready. This information is also accessible via the EOC pin, but with reversed polarity.

Status bit [4:3]: always [0:0]

Status bit 2 / memory check: During power up the AMS 5935 performs a memory check. If the check is completed without errors, the bit is "0". If it is "1", it indicates an uncontrolled change of a memory register and the sensor might not work properly.

Status bit 0 / overflow indication: This bit indicates a signal overflow. It is "0", if the sensor data is valid. If it is "1", the applied pressure exceeds the sensor's pressure range.

status bit	7	6	5	4	3	2	1	0
default	0	1	0	0	0	0	0	0
meaning	-	-	0, if sensor data is ready	–	–	0, if integrity test was passed	-	0, if sensor is not in overflow

Table 5: AMS 5935's status byte

Calculating the current pressure and temperature from the digital values

The digital pressure value is given by the bytes 2, 3 and 4, with byte 2 being the most significant byte and byte 4 the least significant one. In the same way, the temperature value consists of the bytes 5, 6 and 7. In order to generate the desired information on pressure and temperature the digital output values have to be converted into physical units.

The current pressure in the desired physical unit (e.g. mbar) is calculated from the digital pressure value using the following equations:

$$p = \frac{Digoutp(p) - Digoutp_{min}}{Sensp} + p_{min} \qquad \text{with} \qquad Sensp = \frac{Digoutp_{max} - Digoutp_{min}}{p_{max} - p_{min}} \qquad (1)$$

wherein

p is the current pressure in the desired physical unit (e.g. mbar, Pa),

p_{min} and p_{max} are the specified minimum and maximum pressure values in the desired physical unit (e.g. in mbar) depending on the specific pressure range (see *Table 1* and *Table 2*)

Digoutp(p) is the current digital 24-bit pressure measurement value in counts,

Digoutp$_{min}$ is the digital pressure measurement value at the minimum specified pressure in counts,

Digoutp$_{max}$ is the digital pressure measurement value at the maximum specified pressure in counts,

Sensp is the sensitivity of the pressure sensor (e.g. in counts/mbar, counts/Pa).

The current sensor temperature in °C is calculated from the digital temperature output value using the following equation:

$$T = \frac{(DigoutT(T) \cdot 165)}{2^{24}} - 40 \qquad (2)$$

Therein *T* is the current sensor temperature in °C and *DigoutT(T)* is the current 24 bit digital temperature output value in counts.

Example:

At the digital output of an AMS 5935-0005-D-B (-5 … 5 mbar bidirectional differential sensor) the following data bytes 1 … 7 are read:

Byte 1: $0x40_{Hex}$ Byte 2: $0xB9_{Hex}$ Byte 3: $0x12_{Hex}$ Byte 4: $0xD4_{Hex}$ Byte 5: $0x62_{Hex}$ Byte 6: $0xAA_{Hex}$
Byte 7: $0x33_{Hex}$

Byte 1 is the status byte and not necessary for the calculation.

Taking bytes 2, 3 and 4 the current 24-bit digital pressure value is:

$$\textbf{\textit{Digoutp(p)}} = B9\,12\,D4_{Hex} \text{ counts} = 12128980_{Dec} \text{ counts}$$

and with byte 5, 6 and 7 the digital temperature value is:

$$\textbf{\textit{DigoutT(T)}} = 62\,AA\,33_{Hex} \text{ counts} = 6466099_{Dec} \text{ counts}$$

For AMS 5935-0005-D-B the following values are specified:

p_{min} = -5 mbar, p_{max} = 5 mbar and $\textbf{\textit{Digoutp}}_{min} = 0.1 \cdot 2^{24}$, $\textbf{\textit{Digoutp}}_{max} = 0.9 \cdot 2^{24}$

Using these values and equation (1) the current pressure in mbar can be calculated:

$$\textbf{\textit{p}} = \frac{(12128980 - 0.1 \cdot 2^{24}) \text{ counts}}{(0.8 \cdot 2^{24} / 10) \text{ counts / mbar}} + (-5) \text{ mbar} = 2.787 \text{ mbar}$$

Using equation (2), the current sensor temperature in °C is calculated as:

$$\textbf{\textit{T}} = \frac{(6466099 \cdot 165) \text{ counts} \cdot °C}{2^{24} \text{ counts}} - 40 \text{ °C} = 23.6 \text{ °C}$$

DIMENSIONS AND PINOUT

AMS 5935 pressure sensors come in a dual-in-line package (DIP-08, width: 600 mil) for assembly on printed circuit boards (PCB).

The pinout and dimensions of AMS5935's dual-in-line package are shown in *Figure 9* for sensor types with vertical metal tubes (for connection with pressure hoses) and in *Figure 10* for sensor types for manifold assembly (-N option without tubes).

Pinout and pressure connection:

Differential types:

Pressure port 2
8 7 6 5
Pressure port 1
1 2 3 4
PIN marking

Absolute, barometric types:

8 7 6 5
Pressure port 1
1 2 3 4
PIN marking

Pin	Description
1	GND
2	VCC
3	SDA/MOSI
4	SCL/SCLK
5	EOC
6	MISO
7	N.C.
8	SS

Package dimensions:

Side view :

2 Tubes OD = 3.175 [0.125]
12.4 [0.49]
4.3 [0.17]
Ceramic substrate typ. 1.0 [0.04]
8.6 [0.34]
Ceramic lid 9.4x13.97 [0.37x0.55]
0.5 [0.02]
8 pins width $0.25^{\pm0.005}$ [$0.01^{\pm0.0002}$]

Top view :

15.24 [0.60]
2.54 [0.1]
3.81 [0.15]
15.24 [0.60]
14.73 [0.58]
8.13 [0.32]
5.08 [0.2]
3.05 [0.12]
9.40 [0.37]

all dimensions in mm [inch], tolerances: ±0.1 mm unless otherwise noted

Figure 9: **Dimensions of sensor types with vertical metal tubes**

Pinout and pressure connection:

Differential types:

Pressure port 2

8 7 6 5

Pressure port 1

1 2 3 4

PIN marking

Absolute, barometric types:

8 7 6 5

Pressure port 1

1 2 3 4

PIN marking

Pin	Description
1	GND
2	VCC
3	SDA/MOSI
4	SCL/SCLK
5	EOC
6	MISO
7	N.C.
8	SS

Package dimensions:

Side view :

Ceramic substrate typ. 1.0 [0.04]

Ceramic lid 9.4x13.97 [0.37x0.55]

8 pins width 0.25$^{\pm0.005}$ [0.01$^{\pm0.0002}$]

2.54 [0.1]   4.3 [0.17]

8.6 [0.34]

0.5 [0.02]

Top view :

15.24 [0.60]

3.81 [0.15]

Bore diameter = 0.50 [0.02]

15.24 [0.60]

14.73 [0.58]

8.13 [0.32]

5.08 [0.2]

3.05 [0.12]

9.40 [0.37]

all dimensions in mm [inch], tolerances: ±0.1 mm unless otherwise noted
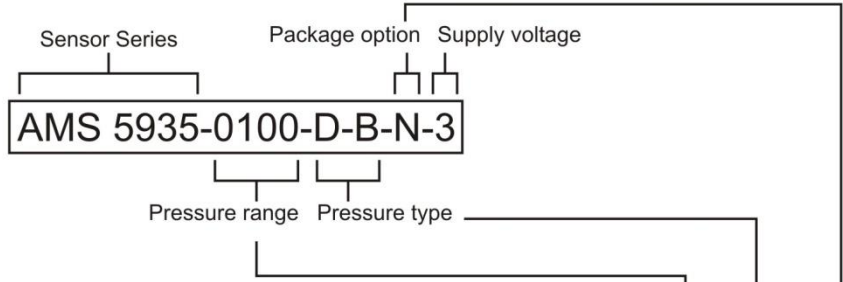
Figure 10: **Dimensions and pinout of AMS 5935 for manifold assembly (-N option without tubes)**

Notes on "Dimensions and Pinout" (*Figure 9* and *Figure 10*):

1) Except for pin 7 unused pins have to be left unconnected.

2) Packages with SMT Pins (J-Lead) are available on request.

3) Relative / gage variants with one single tube are available on request.

4) Pressure port 2 applies pressure to the piezoresistive silicon sensing element's backside and is therefore compatible with non-corrosive liquids. For media compatibility of pressure port 1 and port 2 see "Specification notes", 7 and 8.

5) For automatic soldering (lead-free wave or reflow soldering) of AMS 5935 a peak temperature of 250°C for a maximum of 20 to 30 seconds is recommended. A typical temperature profile for Pb-free assembly is given by IPC/JEDEC J-STD-020D, Table 5-2.

INFORMATION FOR ORDERING

Ordering code:

Sensor Series				Package option	Supply voltage	

AMS 5935-0100-D-B-N-3

Pressure range   Pressure type

Pressure range code	mbar	Pa	psi	inH$_2$O
0001	1.25	125	0.018	0.501
0002	2.5	250	0.036	1.003
0005	5	500	0.073	2.007
0010	10	1000	0.145	4.014
0020	20	2000	0.290	8.029
0035	35	3500	0.507	14.051
0050	50	5000	0.725	20.073
0100	100	10000	1.450	40.146
0200	200	20000	2.901	80.292
0350	350	35000	5.076	140.512
0500	500	50000	7.251	200.731
1000	1000	100000	14.50	401.463
1200	1200	120000	17.40	481.755
1500	1500	150000	21.75	602.194
2000	2000	200000	29.01	802.926

Code	Pressure type	Available pressure ranges
D	Differential / relative (gage)	0 ... 2.5 mbar to 0 ... 1 bar
D-B	Bidirectional differential	-1.25 … +1.25 mbar to -1 ... 1 bar
A	Absolute	0 … 500 mbar to 0 ... 2 bar
B	Barometric (absolute)	700 … 1200 mbar

Code	Package option
	Standard package with tubes for hose connection
N	Manifold mount package

ADDITIONAL EQUIPMENT

Ordering code	Description
USB starter kit AMS 5935	A USB starter kit interfacing AMS 5935 to a Windows PC (Windows 10 or 11) via a USB port. It consists of two PCBs and software. The kit can be used for quick and easy evaluation of AMS 5935, data readout, data logging and to change AMS 5935's I^2C address.
AMS 5935 – Arduino PCB	An adapter PCB board, which can be used to interface AMS 5935 with an Arduino Uno. A library and example code for Arduino's IDE is available for download at www.analog-micro.com.
AMS 5935 Arduino Nano Kit	A kit used to interface AMS 5935 to an Arduino Nano directly. It consists of two PCBs, an AMS Arduino Nano Shield and an AMS 5935 Mini PCB, as well as a matching ribbon cable. A library and example code for Arduino's IDE is available for download at www.analog-micro.com.

For more information on additional equipment, see AMS 5935's product page

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