CONTENTS:

1 DESCRIPTION

SP12 is a tyre pressure sensor for air pressure measurements in the range from 100 to 450 kPa, designed for passenger car TPMS applications. SP12 has a digital serial interface for communication with micro controllers, is housed in a 14 pin small outline package and requires no external components. SP12 performs measurements of pressure, acceleration, temperature and supply voltage. A low power oscillator provides wake up and reset signals at regular intervals to a micro controller.

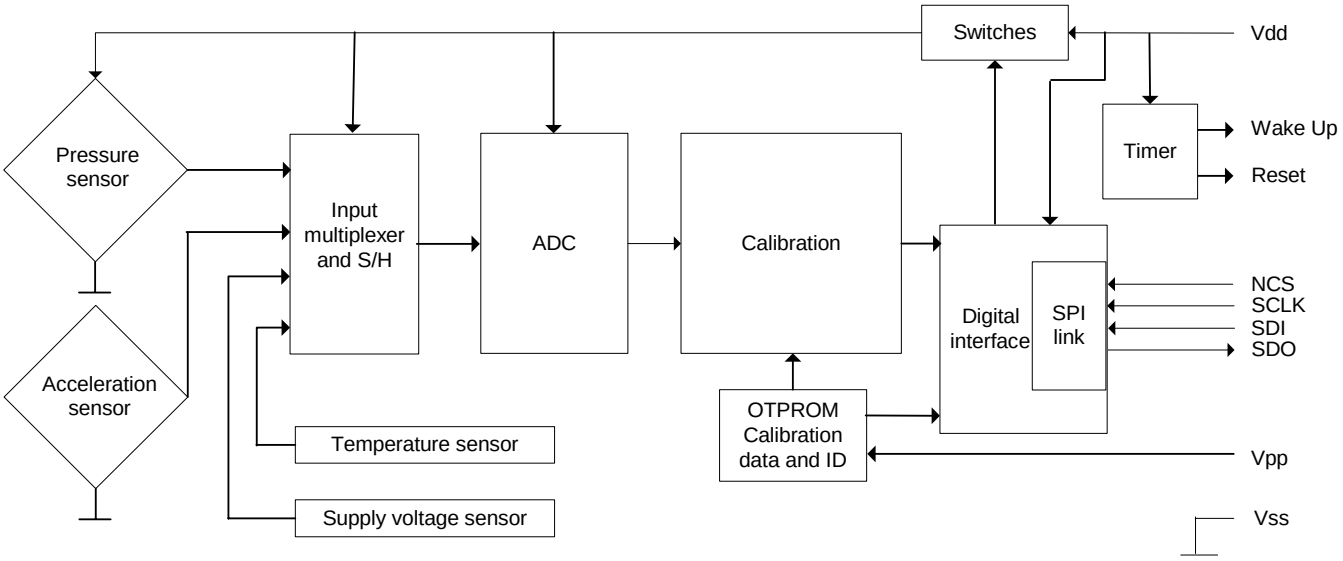


Figure 1 SP12 block diagram.

	Date	Sign	Rev	Reference	Date	Doc	Stamp
Prepared	030815	RoW	**00**	**Archive 9431**	030828	HKW	
Checked	030822	BB	**01**	**EM 10106**	040827		
Approved	030822	ED	**02**	**EM**			

2 ABBREVIATIONS

ESD: ElectroStatic Discharge
SPI: Serial Peripheral Interface
TPMS: Tyre Pressure Monitoring System

3 REFERENCES

REF	DOCUMENT	DOC NO
[1]	Package type 6 laser marking and mechanical dimensions	M4918

Table 1 References.

4 ABSOLUTE MAXIMUM RATINGS

Prolonged exposure to values between recommended operating conditions and absolute maximum ratings might affect the performance or reliability of the device.

PARAMETER	MIN	MAX	UNIT
Input pressure		1400	kPa
Storage temperature 1)	-40	150	^{o}C
Temperature in application 2)	-40	150	^{o}C
Temperature, transient 3)	-40	175	^{o}C
Supply voltage	-0.3	6.0	V
Input voltage, any pin	-0.3	VDD + 0.3	V
Latch-up protection 4)	-100	100	mA
ESD protection (machine model) 5)	-200	200	V
ESD protection (human body model) 6)	-2	2	kV
Mechanical shock		2000	g
Static acceleration		2000	g

Table 2 Absolute maximum ratings.

Note 1) Accumulated time at 150°C not to exceed 500 hours. Solder ability may be affected negative even with less exposure.
Note 2) Accumulated time at 150°C less than 2.5 hours.
Note 3) Time at 175°C less than 3 min. The component withstands standard reflow soldering.
Note 4) According to AEC Q100-004.
Note 5) According to AEC Q100-003.
Note 6) According to AEC Q100-002.

5 RECOMMENDED OPERATING CONDITIONS

PARAMETER	MIN	MAX	UNIT
Temperature range, operational	-40	125	^{o}C
Supply voltage during measurement 1)	2.1	3.6	V
Supply voltage between measurements 2)	1.8	5.5	V
Input pressure 3)	100	450	kPa

Table 3 Recommended operating conditions.

Note 1) Specified range.
Note 2) Operating voltage for the oscillator and digital circuits.
Note 3) All pressure values given in this specification are absolute values (referred to vacuum).

6 MEASUREMENT PERFORMANCE

The ADC in SP12 is an integrating charge balancing converter. Monotonic operation and no missing codes are guaranteed over the full operating range.

6.1 PRESSURE MEASUREMENTS

All specification limits to be understood as 4σ values. The specified values reflect the situation with an ideal voltage source (0Ω internal resistance).

PARAMETER		SPECIFICATION			AMBIENT CONDITION		
	Unit	Min	Typ	Max	Temperature [°C]	Pressure [kPa]	Supply voltage [V]
Input range	kPa	100	--	450	-40 to 125	100 – 450	2.1 – 3.6
Resolution	kPa/lsb		1.37		-40 to 125	100 – 450	2.1 – 3.6
Measurement error 1)	kPa	-8.5		8.5	0 to 50	200 – 400	2.1 – 3.6
	kPa	-10		10	-20 to 70	200 – 400	2.1 – 3.6
	kPa	-17		17	-40 to 100	200 – 400	2.1 – 3.6
	kPa	-25		25	100 to 125	200 – 400	2.1 – 3.6
	kPa	-20		20	0 to 50	100 – 450	2.1 – 3.6
	kPa	-25		25	-20 to 70	100 – 450	2.1 – 3.6
	kPa	-30		30	-40 to 100	100 – 450	2.1 – 3.6
	kPa	-40		40	100 to 125	100 – 450	2.1 – 3.6
Measurement time	ms			6			

Table 4 Pressure measurement performance.

Note 1) This parameter may be influenced by the internal resistance of the supply voltage source.

6.2 TEMPERATURE MEASUREMENTS

All specification limits is to be understood as 5σ values.

PARAMETER		SPECIFICATION			AMBIENT CONDITION	
	Unit	Min	Typ	Max	Temperature [°C]	Supply voltage [V]
Input range	°C	-40		125	-40 to 125	2.1 – 3.6
Resolution	°C/lsb		1		-40 to 125	2.1 – 3.6
Deviation from actual temperature 1)	°C	-4		4	0 to 50	2.5 – 3.6
	°C	-5		5	-40 to 100	2.5 – 3.6
	°C	-8		8	+100 to 125	2.5 – 3.6
	°C	-7		7	0 to 50	2.1 – 2.5
	°C	-10		10	-40 to 125	2.1 – 2.5
Measurement time	ms			1.5		

Table 5 Temperature measurement performance.

Note 1) Specification valid provided use of formula describing known deviation from actual temperature.

The temperature read from SP12 is known to have a deviation from actual temperature. A correction term is given by:

$$\Delta T_{corr} = -0.92 + 0.004 * T_{SP12} + 0.0002 * T_{SP12}^{2}$$

where: T_{SP12} is the temperature reported by SP12, and
ΔT_{corr} is the correction term.

ΔT_{corr} should be subtracted from the temperature reported from SP12 to achieve the accuracy specified in Table 5.

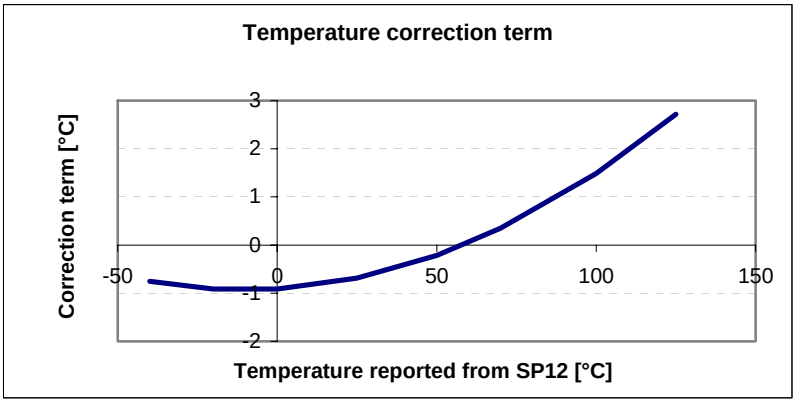


Figure 2 Temperature correction term.

6.3 ACCELERATION MEASUREMENTS

All specification limits to be understood as 4σ values. The specified values reflect the situation with an ideal voltage source (0Ω internal resistance).

PARAMETER		SPECIFICATION			AMBIENT CONDITION	
	Unit	Min	Typ	Max	Temperature [°C]	Supply voltage [V]
Input range	g	-12		115	-40 to 90	2.1 to 3.6
Resolution	g/lsb		0.5		-40 to 90	2.1 to 3.6
Sensitivity accuracy	%	-18.75		18.75	-40 to 90	2.1 to 3.6
	%	-24		24	90 to 125	2.1 to 3.6
Offset	g	-6		6	25	2.1 to 3.6
	g	-8.75		8.75	-40 to 90	2.1 to 3.6
	g	-12		12	90 to 125	2.1 to 3.6
Random error (including quantification error, noise, repeatability) 1)	g	-2		2	-40 to 90	
	g	-4		4	90 to 125	
Acceleration measurement time	ms			6		

Table 6 Acceleration measurement performance.

Note 1) Values reflect 98% of all measurements on one device.

6.4 SUPPLY VOLTAGE MEASUREMENTS

All specification limits to be understood as 4σ values.

PARAMETER		SPECIFICATION			AMBIENT CONDITION	
	Unit	Min	Typ	Max	Temperature [°C]	Supply voltage [V]
Input range 1)	V	1.8		3.6	-40 to 125	1.8 – 3.6
Resolution	V/lsb		0.0184		-40 to 125	2.1 – 3.6
Measurement error	V	-0.1		0.1	-40 to 125	2.1 – 3.6
Delay time between supply voltage measurement command and sampling	ms	2.8	3.5	4.2	-40 to 125	2.1 – 3.6
Delay time between sampling and A/D conversion	ms	8	10	12	-40 to 125	2.1 – 3.6
Supply measurement time	ms			17		

Table 7 Supply voltage measurement performance.

Note 1) The sampling operates down to 1.8 V. The specifications applies to the a/d-conversion.

7 WAKE UP AND RESET OUTPUTS

The SP12 provides two outputs, Wake up and Reset, which may be used to interrupt or reset a micro controller. Each output provides a pulse at regular intervals. The wake up and reset signals are active low outputs.

PARAMETER	MIN	TYP	MAX	UNIT
Wake up period	4.8	6	7.2	s
Wake up width	0.13		2.5	ms
Reset period	41	51	61	min
Reset width	0.13		2.5	ms
Interval timing drift over temperature 1)		0.6	1	%/°C
Interval timing drift over supply voltage 1)		-15	-40	%/V

Table 8 Wake up and Reset outputs.

The SP12 has two oscillators: One low-power oscillator, which runs at about 2.5 kHz, used for interval timing, and one 2 MHz oscillator used for measurements and data transmission.

Due to its very low current consumption, the low-power oscillator is sensitive to temperature and supply voltage variation. To keep the interval lengths constant under different conditions, the low-power oscillator is compared to the 2 MHz oscillator during each measurement, and a correction is applied to the interval count. This operation is called an auto calibration. The stability of the interval depends on the change in temperature or supply voltage since the last measurement.

8 SERIAL INTERFACE

The SPI interface is the communication protocol to the external micro controller. The maximum serial clock frequency is 500kHz.

The SPI consists of a shift register, a command latch and failure latches, and encoder/decoder logic.

8.1 SPI PROTOCOL

When NCS is high, any signals at the *SCLK* and *SDI* pins are ignored, and *SDO* is forced into a high impedance state.

During the *NCS* high-to-low transition, the SPI response word is multiplexed from the latch(es) that was(were) defined by the last command present in the shift register. The *SCLK* pin must be low when *NCS* goes low.

At each clock rising edge after *NCS* has gone low, the response word is serially shifted out of the SP12 at the *SDO* pin, LSB first.

At each clock falling edge after *NCS* has gone low, the new control word is serially shifted into the SP12 at the *SDI* pin, LSB first.

The command bits of the received SPI word are then decoded to determine the destination address for the data bits. After the 8^{th} clock falling edge has occurred, the following *NCS* low-to-high transition causes the data bits stored in the SP12 ASIC SPI shift register to be transferred into the latch whose address was decoded from the SPI shift register command bits.

If the number of clock pulses before *NCS* goes high is different from 0, 8 or 16, a digital filter prevents execution of the received command. (A valid *NCS* pulse with 0 clock pulses will cause the previous command to be executed again)

The Failure Status Indicator (FSI) is a logical OR of all the bits in the status register, except for bit 6. See 8.4 for more about status byte content. The FSI appears at the *SDO* pin after *NCS* has gone low and before *SCLK* goes high (see timing diagram below).

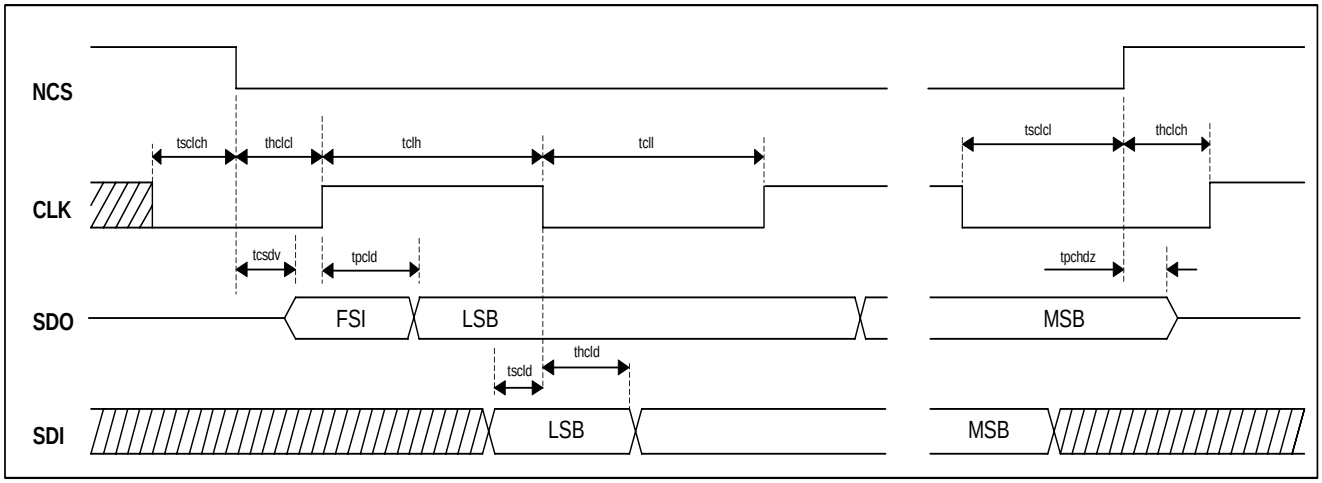


Figure 3 SPI timing diagram.

The FSI is valid only in front of a response byte that contains a measurement result value. If FSI is high, at least one of the error bits in the status byte has been set, and the measurement should be rejected.

Control bytes and response bytes are 8 bits, the content of which depends upon the command given. When a control byte is shifted in, the response byte that is shifted out during the same transition time will be the response byte from the previous command: shift in control byte « n », shift out response byte « n- 1 ». Therefore, each control/response pair requires two full 8-bit shift cycles to complete. The control bytes (commands) are described in Table 10. Some control bytes require an additional data byte. For such command, the data byte must be transmitted first, before the command byte.

8.2 SPI TIMINGS PARAMETERS

SPI (Load capacitor at SDO = 300pF)		**MIN**	**MAX**	**UNIT**
f_{SCLK}	Max. allowed application frequency (50% duty cycle)		500	kHz
t_{SDO_trans}	SDO transition speed, 20% to 80% (with 60pF load capacitor)	5	25	ns
t_{clh}	Minimum time SCLK = HIGH	100		ns
t_{cll}	Minimum time SCLK = LOW	100		ns
t_{pcld}	Propagation delay (SCLK to data edge at SDO valid)		100	ns
t_{csdv}	NCS = LOW to data edge at SDO active		100	ns
t_{sclch}	SCLK low before NCS low (setup time SCLK to NCS edge H/L)	100		ns
t_{hclcl}	SCLK edge L/H after NCS edge H/L	100		ns
t_{scld}	SDI input setup time (SCLK edge H/L after SDI data valid)	20		ns
t_{hcld}	SDI input hold time (SDI data hold after SCLK edge H/L)		20	ns
t_{sclcl}	SCLK low before NCS high	150		ns
t_{hclch}	SCLK high after NCS high	150		ns
t_{pchdz}	NCS edge L/H to SDO at high impedance		100	ns
t_{onNCS}	NCS min. high time	60		µs
	Capacitance at SDI, SDO, SCLK, NCS		10	pF
t_{fNCS}	NCS filter time (Pulses shorter than t_{fNCS} will be ignored)	10	100	ns
	NCS pulse filter [1)]			

Table 9 SPI timing parameters.

Note 1) Digital filter for driver control register latch function. Output latch function is only enabled if positive NCS occurs after 8 CLK cycles (or a multiple of 8) since last negative NCS edge.

8.3 SPI COMMANDS

Commands expected with an additional data byte in front are marked with an "A" in the address column. For commands that require this additional data byte, this byte and the command itself must be sent as one 16 bit word, with the *NCS* being continuously low for 16 *SCLK* cycles. The low-to-high transition of *NCS* then triggers the command

execution. If *NCS* is brought high between the additional data byte and the command, the data byte will be interpreted as a separate command.

COMMAND	CODE	ADDR	RESPONSE	DESCRIPTION
MEASURE _P	0011 0001		Read back command code	Measure pressure
RCPD	0010 1100		Compensated pressure data	Read compensated pressure data
RRPDH	0000 1000		Raw pressure data, high byte	Read raw pressure data, high byte
RRPDL	0000 0100		Raw pressure data, low byte	Read raw pressure data, low byte
MEASURE _A	1000 0101		Read back command code	Measure acceleration
RCAD	1000 0000		Compensated acceleration data	Read compensated acceleration data
RRADH	1000 0001		Raw acceleration data, high byte	Read raw acceleration data, high byte
RRADL	1000 0011		Raw acceleration data, low byte	Read raw acceleration data, low byte
READIDH	0011 1101		ID, high byte	Read ID, high byte
READIDM	0011 1000		ID, mid byte	Read ID, mid byte
READIDL	0011 0100		ID, low byte	Read ID, low byte
MEASURE_T	1010 1101		Read back command code	Measure temperature
RCTMP	1011 0000		Compensated temperature data	Read compensated temperature
MEASURE _B	0010 0101		Read back command code	Measure supply voltage
RCBD	0010 1001		Compensated supply voltage data	Read compensated supply voltage data
RSR	1011 0101		Status register (see also 8.4)	Read status register
READ	1011 1000	A	One byte of shadow register	Read one byte of shadow register (copy of OTP coefficients)
OTP_PWR 1)	11110110	A	Read back command code	Turn OTP power on/off
RADDR	1100 0001	A	Read register at applied address	Read applied address (test of SPI)
STANDBY	0000 0001		Last response repeated	Go in standby mode and shift out the response from the previous measurement command
LDOTP 2)	1011 1100		Read back command code	Reset of SP12: Load OTP content to shadow register

Table 10 SP12 SPI commands.

Note 1) For test purposes only. A = 0 turns OTP power off. A <> 0 turns OTP power on.
Note 2) For test purposes only.

If an invalid command is received, no action will be taken and the response word will be all 0's (00 hex). The three bytes of the ID (Identifier) code are programmed in the SP12 PROM.

8.4 STATUS BYTE

BIT	DESCRIPTION	NOTE
0	Overflow/ Underflow	ADC or compensation
1	Parity error in PROM data	
2	Checksum error in shadow register	
3	PROM reload / Internal reset	Set during reset and PROM Reload (used to indicate complete reset sequence)
4	Unspecified meas accuracy due to low supply voltage	0: Supply voltage ok 1: Low supply voltage (Vdd < 2.1)
5	Sensor fault (Mechanical integrity of pressure and acceleration sensors and interchip bonding wires)	0 : No error 1 : Pressure sensor, acceleration sensor or interchip bond wires broken
6	Direction of positive acceleration (not included in FSI calculation)	0 : SP12 will measure pos acc when mounted with the inlet hole pointing away from centre of rotation (default) 1 : SP12 will measure pos acc when mounted with the inlet hole pointing towards centre of rotation
7	Measurement in progress	0 : Measurement completed (data can be read) 1 : Measurement in progress (data not available)

Table 11 Status byte contents.

8.5 PRESSURE BYTE

The absolute pressure, in kPa, is obtained by multiplying the value in this byte by the given pressure resolution in table Table 4, and adding 100 kPa (fixed offset value).

8.6 ACCELERATION BYTE

The acceleration, in g's, is obtained by multiplying the value in this byte by 0.5, and subtracting 12.

8.7 TEMPERATURE BYTE

The temperature, in °C, is obtained by subtracting 50 from the value in this byte.

The allowed range for this byte is 10-175, corresponding to temperatures from -40 to +125°C (for which the accuracy is specified). Note that the temperature byte may show values outside this range, which then have an undefined accuracy.

8.8 SUPPLY VOLTAGE BYTE

The supply voltage, in volts, is obtained by multiplying the value in this byte by 0.0184, and adding 1.73.

9 DIGITAL I/O CHARACTERISTICS

PARAMETER		SPECIFICATION			AMBIENT CONDITIONS		
	Unit	Min	Typ	Max	Temperature [°C]	Supply voltage Vdd [V]	Max current [mA]
Input logic low (VIL)	V			0.2·Vdd	-40 to 125	1.8 to 3.6	
Input logic high (VIH)	V	0.8·Vdd			-40 to 125	1.8 to 3.6	
Input leakage	µA	-1		1	-40 to 125	1.8 to 3.6	
Output logic low	V		0.1	0.2	-40 to 125	1.8 to 3.6	1
Output logic high	V	Vdd – 0.25			-40 to 125	1.8 to 3.6	1

Table 12 Digital I/O characteristics.

10 POWER-ON RESET

To guarantee a power-on reset, VDD must be at 0 V for a minimum of 1.0 ms. This will cause a hardware reset, and start a 10 ms timer. After the 10 ms, a negative pulse on the RESET pin will be generated and the PROM will be read. If this is successful, the SP12 will enter normal operation. If the PROM reading is not successful, error handling will be as described in section 12. See Table 13 for SP12 power-on reset specifications.

PARAMETER		SPECIFICATION			AMBIENT CONDITIONS
	Unit	Min	Typ	Max	Temperature [°C]
VDD level to initiate power-on reset	V			0	
VDD level **not** to initiate power-on reset	V	1.0			
VDD rise time (to 2.2V or higher)	µs	0.1			
Power-on reset duration	ms		25	60	25
				150	-40 to 125
VDD required to complete power-on reset	V	2.2			
Delay before power-on reset pulse	ms	0.83		12.5	
Duration of power-on reset pulse	ms	0.16		2.5	

Table 13 Power-on reset specifications.

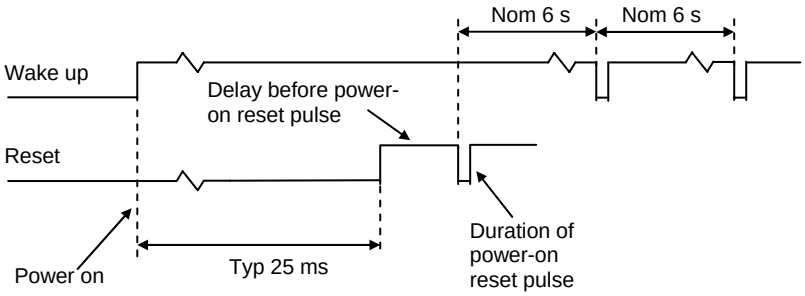


Figure 4 Typical Wake up and Reset signals during a power-on reset. Time increases towards the right.

11 CURRENT CONSUMPTION

11.1 STANDBY CURRENT

The standby current is the current drawn by the SP12 when only the low-power oscillator and the interval counters are running.

11.2 MEASUREMENT CURRENT

During measurement, various analog modules will be switched on and off to minimize total current consumption.

PARAMETER	AMBIENT CONDITION		TYP	MAX	UNIT
	VDD [V]	TEMP [°C]			
Supply current in standby mode	2.1	25	0.3	0.45	uA
	2.1	90	2.0	3.0	uA
	2.1	120	11	16.5	uA
Supply current, all analog and digital modules active	2.1	25	2.1	2.9	mA
	2.1	90	2.2	3.0	mA
	2.1	120	2.2	3.1	mA
Supply current, digital activity incl. MCLK[1)]	2.1	25	0.5	0.8	mA
	2.1	90	0.5	0.8	mA
	2.1	120	0.6	0.9	mA

Table 14 Supply currents, Vdd = 2.1V.

Note 1) Maximum values cover MCLK frequencies up to 2.0 MHz.

PARAMETER	AMBIENT CONDITION		TYP	MAX	UNIT
	VDD [V]	TEMP [°C]			
Supply current in standby mode	3.0	25	0.4	0.6	uA
	3.0	90	2.3	3.45	uA
	3.0	120	13	19.5	uA
Supply current, all analog and digital modules active	3.0	25	2.7	3.5	mA
	3.0	90	2.8	3.7	mA
	3.0	120	2.8	3.8	mA
Supply current, digital activity incl. MCLK[1)]	3.0	25	0.6	1.0	mA
	3.0	90	0.6	1.1	mA
	3.0	120	0.7	1.2	mA

Table 15 Supply currents, Vdd = 3.0V.

Note 1) Maximum values cover MCLK frequencies up to 2.0 MHz.

12 ERROR HANDLING AND RECOVERY

12.1 PROM DATA

The PROM contains calibration data and the identification code (ID). The PROM is read at power-on reset, when its contents are copied to the shadow register. The PROM contains one parity bit. If a parity error occurs during PROM reading, the SP12 will enter the PROM Reload state, as described in section 12.2.

12.2 PROM RELOAD

In this state, the SP12 will read the PROM contents again with 1 second intervals until a successful read is completed. The PROM reading can fail for two reasons:

- Parity error in PROM data
- Reading not allowed due to supply voltage below minimum for read operation

The FSI will be set if a command is activated (via SPI) while the SP12T is in the PROM Reload state.

12.3 SHADOW REGISTER PROTECTION

Immediately after copying the PROM contents to the shadow register, a 16 bit CRC is calculated using the CCITT polynomial. This checksum is stored with the data, and is verified for each measurement cycle thereafter. If an error is detected, the SP12 will enter PROM Reload/Reset state.

12.4 LOW SUPPLY VOLTAGE

A supply voltage below 2.1 V (nominal) has two consequences:

- Reading of the PROM is not allowed
- The measurement accuracy cannot be guaranteed

The SP12 uses a separate circuit with an output signal called VMIN, to detect this condition. VMIN = 1 will occur if VDD<2.1 ±0.1V.

If a measurement is requested while VMIN =1 bit 4 will be set in the status register. See section 8.4.

If low supply voltage causes the information in the shadow register to be corrupted, the SP12 will enter PROM Reload state as described in section 12.2.

12.5 HIGH TEMPERATURE

If high temperature causes the information in the shadow register to be corrupted, the SP12 will enter PROM Reload state as described in section 12.3.

12.6 OVERFLOW/ UNDERFLOW

The overflow/ underflow bit in the status register will be set by an overflow or underflow in the ADC or compensation module. For temperature and supply voltage measurements, ADC overflow will not saturate the compensated output value.

For pressure measurements the over-/underflow bit will be set when the compensated output falls below 56.2 kPa, although the output value will saturate at 00 for pressures below 100 kPa.

13 MECHANICAL DESCRIPTIONS

13.1 SP12 PIN OUT

PIN NO	NAME	FUNCTION	NOTE
1	WAKE UP	Wake up output signal	
2	RESET	Reset output signal	
3	TEST/GND	Test in fabrication	Grounded in application
4	VSS	Connected to ground	Grounded in application
5	NC	Not in use	Grounded in application
6	DIG IN/GND	Digital input in fabrication	Grounded in application
7	VSS	Connected to ground	Grounded in application
8	VSS	Connected to ground	Grounded in application
9	VDD	Supply voltage	
10	VPP	Programmation voltage	Do not connect
11	SDI	Serial data input	
12	SCLK	Serial clock input	
13	SDO	Serial data output	
14	NCS	Negative chip select input	

Table 16 SP12 pin out.

13.2 SP12 PACKAGE

SP12 comes in package type 6 (with the pressure inlet hole at the top side).

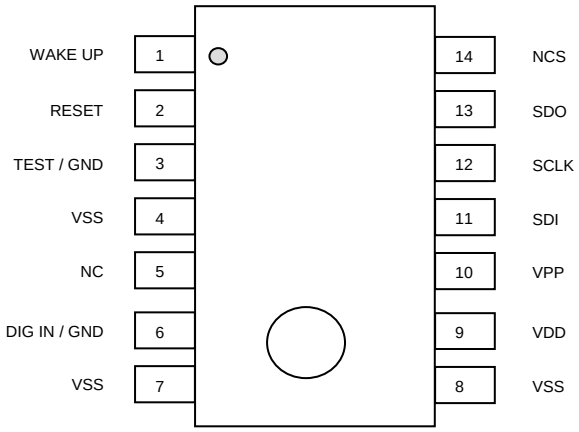
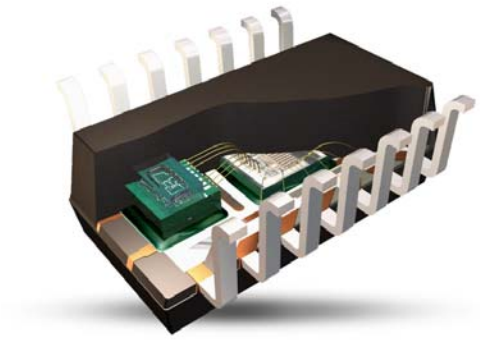


Figure 5 SP12 package (top view).

13.3 MECHANICAL DIMENSIONS AND LABELLING

Refer to [1].



14 DOCUMENT HISTORY

REV	PARAGRAPHS	DESCRIPTION
00		This is the first issue of TS1068.
01		Typical measurement performance plots moved to application note.
01	6.2	"…ΔTcorr should be added to the temperature reported…" changed to "…ΔTcorr should be subtracted from the temperature reported…"
01	8.1	FSI description updated.
01	8.5	Updated.

Table 17 Document history.