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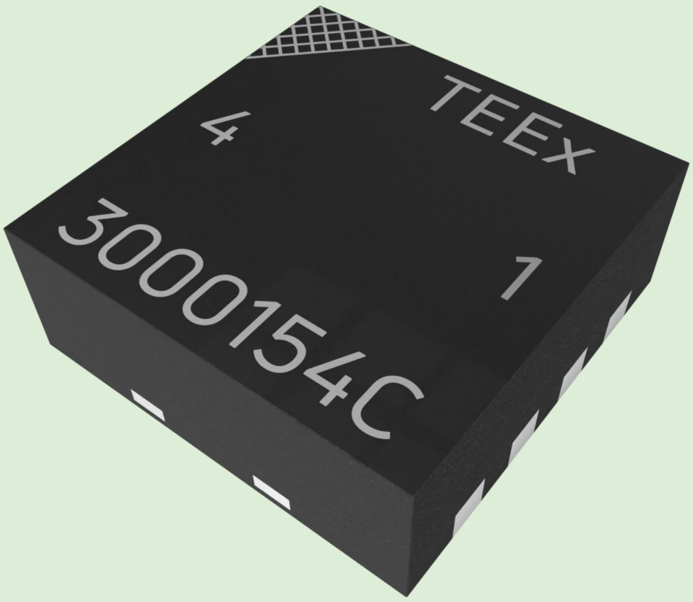
Datasheet TEE501

Digital Temperature Sensor



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TEE501

Digital Temperature Sensor

The TEE501 digital temperature sensing element meets highest requirements in terms of accuracy and reliability. Its diverse applications range from industrial and building automation to medical devices or white goods. A footprint of only 2.5 x 2.5 mm and integrated pull-up resistors facilitate the design-in of the TEE501.

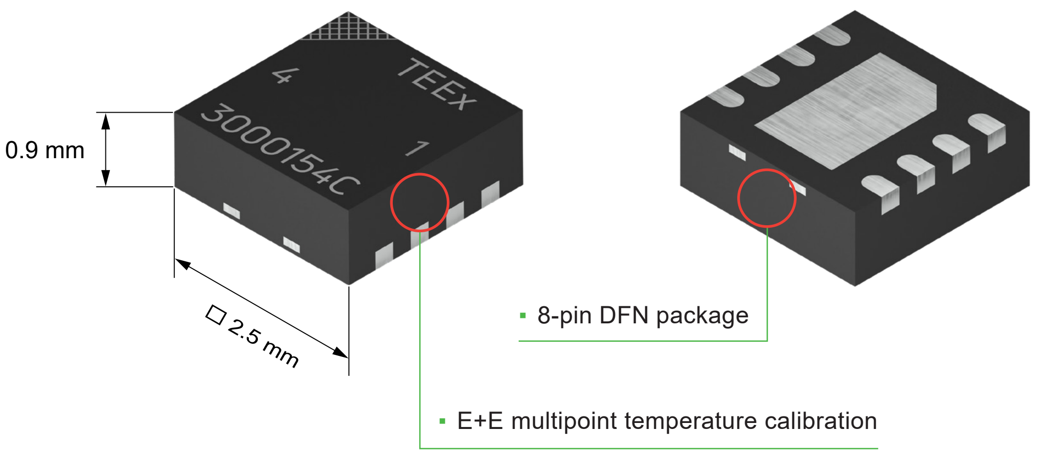
The DFN 8-pin package allows up to 8 devices on one I^2C interface. Furthermore, the TEE501 convinces with an operating range from -40 to 135°C and an accuracy of up to ±0.2 °C, which makes it an ideal solution for demanding measuring tasks.

Key Features

- Accuracy up to ±0.2 °C
- Supply voltage 2.35 - 3.60 V
- 8-pin DFN package
- I^2C interface with pin-selectable addresses
- Integrated I^2C pull-up resistors
- I^2C glitch suppression
- I^2C interface with direct 16 bit integer output
- Excellent repeatability

Typical Applications

- Automotive industry
- Building automation
- Consumer electronics
- Home appliances
- Industrial automation
- Medical devices
- Smart home
- Wearable devices
- White goods



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Acronym	Meaning
A	Ambient
B	Bus
CDM	Charged Device Model
ESD	Electrostatic Discharge
HBM	Human Body Model
MEAS	Measurement, Measuring
PORI	Power On Reset, Idle Mode
PU	Pull-up
POR	Power On Reset
PORP	Power On Reset, Periodic Mode
PUPE	Pull-up external
PUPI	Pull-up internal
PWRU	Power Up
T	Temperature

Table 1: List of TEE501 specific acronyms

1 Pin Configuration

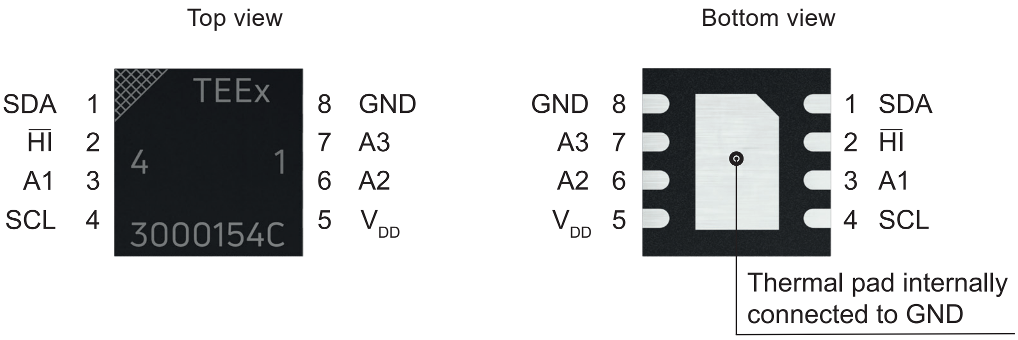

Figure 1: DFN8 pin configuration

Pin	Name	Pin Type	Description
1	SDA	I/O with pull-up	Serial data line for I^2C communication
2	$\overline{HI}$	Output open drain	Indicates invalid measurement[1)]
3	A1	Input high-Z	I^2C device address pin, bit 1 of the 7 bit address; do not leave floating
4	SCL	I/O with pull-up	Serial clock line for I^2C communication
5	V_{DD}	Power	Positive supply pin
6	A2	Input high-Z	I^2C device address pin, bit 2 of the 7 bit address; do not leave floating
7	A3	Input high-Z	I^2C device address pin, bit 3 of the 7 bit address; do not leave floating
8	GND	Power	Ground (internally connected to thermal pad)

1) If unused see pin description ($\overline{HI}$ pin).

Table 2: TEE501 pin assignment

2 Typical Application

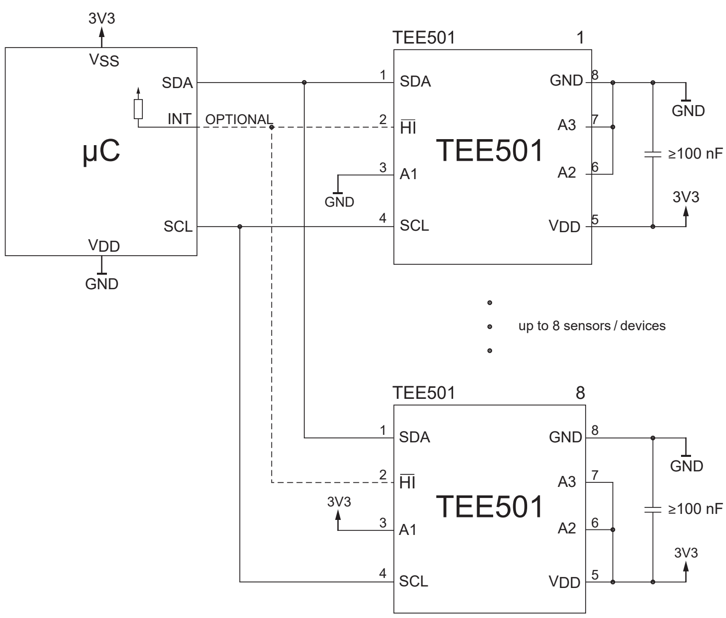

Figure 2: Typical application schematic

3 Specification

3.1 Temperature Sensor

PARAMETER	CONDITION	MIN	TYP	MAX	UNIT
Operating Range		-40		135	°C
Accuracy			0.2	See Figure 3	°C
Resolution[1)]	13 bit		0.01		°C
Repeatability[2)]	13 bit		0.03		°C
Response time[3)]	τ_{63}	2			s
Long Term Drift			<0.03		°C/yr

1) Resolution is chosen by the corresponding measurement command.
2) The stated "Noise / Repeatability" is 3 times the standard deviation (3σ) of multiple consecutive measurement values at constant environmental conditions.
3) Time for achieving 63 % of a step function, valid at 25°C and 1m/s airflow.
The actual response time in application strongly depends on the surrounding of the sensor in the final application (heat conductivity of sensor substrate, dead volume, …).

Table 3: Temperature sensor parameters

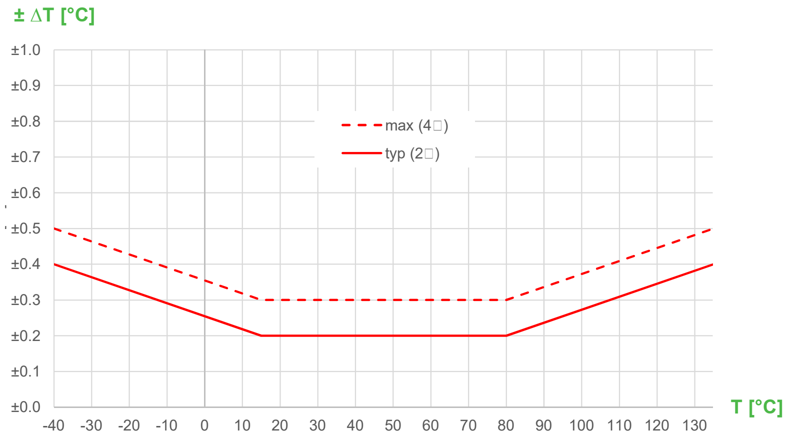

Figure 3: Temperature sensor accuracy

3.2 Recommended Operating Conditions

The TEE501 sensor can be used in the temperature range -40°C…+135°C.

4 Electrical Characteristics

4.1 Absolute Maximum Ratings

The absolute maximum ratings as given in Table 4 are stress ratings only and give additional information. Functional operation of the device at these conditions is not implied. Exposure to absolute maximum rating conditions for extended periods may affect the device reliability (e.g. hot carrier degradation, oxide breakdown).

PARAMETER	SYMBOL	MIN	MAX	UNIT
Power supply	V_{DD}	-0.3	3.6	V
Digital I/O pins	V_{LOGIC}	-0.3	5.0	V
Input current on any pin	I_{IN}	-50	50	mA
Storage temperature	T_{STG}	-55	150	°C
ESD HBM[1)]	ESD_{HBM}	-	4	kV
ESD CDM[2)]	ESD_{CDM}	-	750	V

1) Human Body Model according to AEC-Q100-002
2) Charged Device Model according to AEC-Q100-011

Table 4: TEE501 absolute maximum ratings

4.2 Electrical Specification

Typical values correspond to V_{DD} = 3.3 V and T_A = 25 °C.
Min. and max. values are valid in the full temperature range -40 °C … 135 °C and at declared V_{DD} levels, unless otherwise noted.

PARAMETER	SYMBOL	CONDITION / COMMENT	MIN	TYP	MAX	UNIT
Supply Voltage	V_{DD}		2.35	3.0	3.6	V
POR voltage periodic mode	V_{PORP}	Static power supply	2.10	2.20	2.35	V
POR voltage idle mode	V_{PORI}	Static power supply		1.8		V
Supply current	I_{DD}	Single mode (idle)[1)]		6		µA
		Periodic mode[1)]		80		µA
		Measuring T, Calculation		900		µA
Thermal resistance	R_{TH}	Dependent on PCB layout and enviromental conditions		150		K/W

1) Without I^2C communication and when not measuring.

Table 5: General operation

PARAMETER	SYMBOL	CONDITION / COMMENT	MIN	TYP	MAX	UNIT
Input voltage	V_{IL}	Low level			$0.3*V_{DD}$	V
	V_{IH}	High level	$0.7*V_{DD}$		V_{DD}	V
Output voltage	V_{OL}	Current into pin: I_{OL}= 4.0 mA	0	0.25	0.40	V
	V_{OH}	High level → open drain				
Internal pull-up resistor	R_{PUPI}	V_{DD}=3.60 V & pin voltage = $0.7*V_{DD}$		25		kΩ
		V_{DD}=3.30 V & pin voltage = $0.7*V_{DD}$		27		kΩ
		V_{DD}=3.00 V & pin voltage = $0.7*V_{DD}$		30		kΩ
		V_{DD}=2.35 V & pin voltage = $0.7*V_{DD}$		34		kΩ
External pull-up resistor	R_{PUPE}	At I²C lines, pull-up current ≤4.0 mA @ 3.3 V	0.725	4.7		kΩ
Capacitive bus load	C_B	Standard			400	pF
		Fast mode			400	pF
		Fast mode plus			177	pF

Table 6: I²C communication pins SCL & SDA

PARAMETER	SYMBOL	CONDITION / COMMENT	MIN	TYP	MAX	UNIT
Input voltage	V_{IL}	Low level			$0.3*V_{DD}$	V
	V_{IH}	High level, 5V tolerant input	$0.7*V_{DD}$	V_{DD}	5.0	V
Input leakage current	I_{VDD}	Voltage @pin = 0…V_{DD}	-10	0	+10	µA
	I_{I5V}	Voltage @pin = V_{DD}…5 V		TBD		µA
Output resistance	R_{OH}	Voltage @pin = V_{DD}-0.4 V		116		Ω
	R_{OL}	Voltage @pin = 0.4 V		100		Ω

Table 7: I/O pins

PARAMETER	SYMBOL	CONDITION / COMMENT	TYP	UNIT
Power-up time	t_{PWRU}	After V_{DD} > V_{PORP}, exclude measurement at power-up	1.1	ms
Reset time	t_{RESET}	Any reset except power-up	0.9	ms
T Measurement	t_T	8 bit resolution	0.4	ms
		9 bit resolution	0.7	ms
		10 bit resolution	1.3	ms
		11 bit resolution	2.4	ms
		12 bit resolution	4.6	ms
		13 bit resolution	9.0	ms
		14 bit resolution	17.9	ms
Measurement calculation	t_{CALC}	After every measurement	1.2	ms
SCL SDA input filter	t_{spike}	Short voltage spikes are ignored	25	ms

Table 8: General timing

Subsequently, the typical time from V_{DD} > V_{PORP} to measurement ready in the standard configuration is:

$t_{RDY} = t_{PWRU} + t_{MEAS} = t_{PWRU} + t_T + t_{CALC} = 11.3$ ms

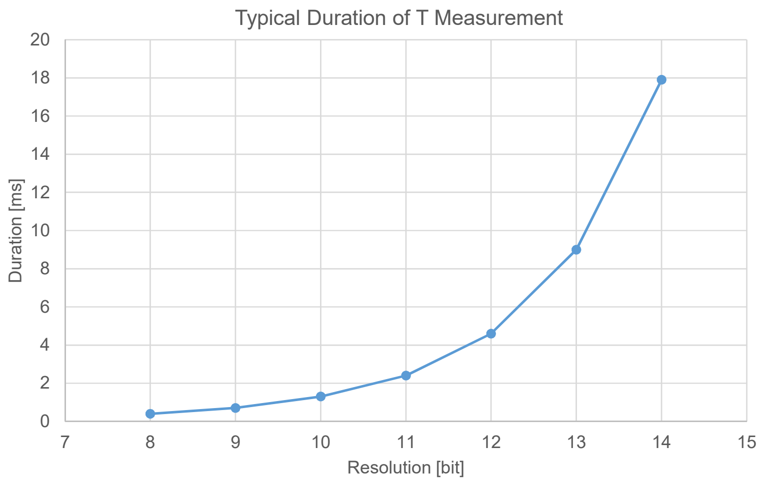

Figure 4: Measurement duration

# OF BITS	RESOLUTION [°C]
14	0.01
13	0.01
12	0.02
11	0.06
10	0.11
9	0.21
8	0.42

Table 9: Measurement resolution

5 Interface

5.1 Supply Pins (V_{DD}, GND)

The supply pins must be equipped with a bypass ceramic capacitor of at least 100 nF.

Sensor Power-up

As soon as V_{DD} exceeds the POR voltage V_{PORP}, the device gets initialized. After t_{PWRU}, the initialization procedure is completed and a single shot measurement is carried out automatically. After the measurement time (t_T+t_{CALC}) the measured values are available at the I^2C interface. The $\overline{HI}$ pin indicates the availability of a valid temperature measurement after power-up (see chapter 1 Pin Configuration).

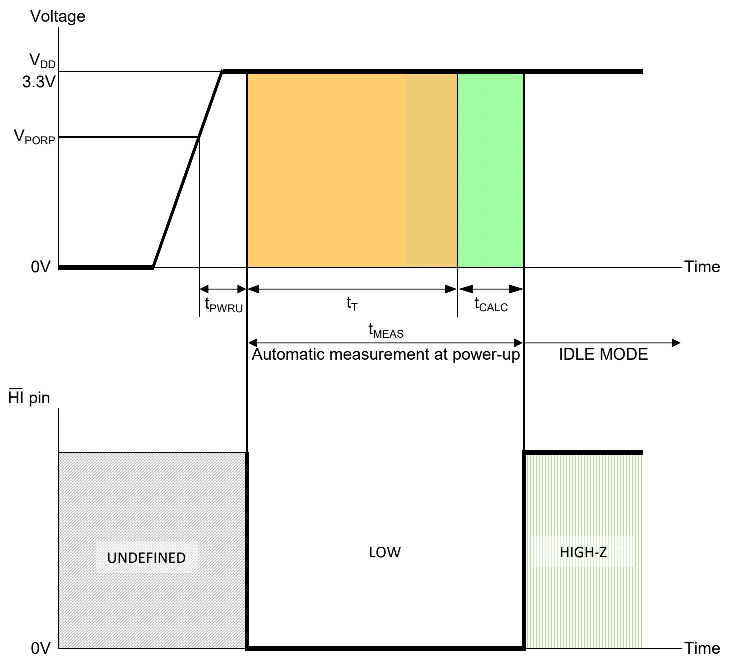

Figure 5: Sensor behaviour at power-up

5.2 I²C Communication

The I²C communication is based on the NXP UM10204 I²C bus specification and user manual[1].
The TEE501 supports the modes “standard“ (100 kHz), “fast mode“(400 kHz) and “fast mode plus” (1 000 kHz).
The sensor works as SLAVE and needs to be queried by a MASTER.

Please consider self-heating due to a low R_{PU} when the sensor has to sink the pull-up current. In this case, the residual voltage on the SCL or SDA pin briefly generates a power loss in the sensor.
Example: 4mA * 0.4V = 1.6mW

5.3 I²C Address Pins

The sensor‘s I²C base address is 0x40 (without R/$\overline{W}$ bit). Pins A1...A3 define the I²C base address.

					PIN 7	PIN 6	PIN 3		SLAVE Address (unshifted)	SLAVE Address (with $\overline{W}$)	SLAVE Address (with R)
					A3	A2	A1	R/$\overline{W}$			
Bit #	7	6	5	4	3	2	1	0			
	1	0	0	1	0	0	0	0/1	0x48	0x90	0x91
	1	0	0	1	0	0	1	0/1	0x49	0x92	0x93
	1	0	0	1	0	1	0	0/1	0x4A	0x94	0x95
	1	0	0	1	0	1	1	0/1	0x4B	0x96	0x97
	1	0	0	1	1	0	0	0/1	0x4C	0x98	0x99
	1	0	0	1	1	0	1	0/1	0x4D	0x9A	0x9B
	1	0	0	1	1	1	0	0/1	0x4E	0x9C	0x9D
	1	0	0	1	1	1	1	0/1	0x4F	0x9E	0x9F

1) Revision 7, 1 October 2021, download from https://www.nxp.com/webapp/Download?colCode=UM10204&location=null.
The document is located behind a login access barrier.

5.4 $\overline{\text{HI}}$ Pin

The $\overline{\text{HI}}$ pin indicates that the recent T measurement was invalid:

a. Recent measurement was:
   i. valid → pin = high-Z
   ii. invalid → pin = LOW
   The status of each measurement (valid/invalid) can be read out from the status register 2.
b. During power-up until the start-up measurement and calculation is finished (please refer to Figure 5 in chapter 5.1 Supply Pins.)

NOTICE

If the $\overline{\text{HI}}$ pin is not used, connect it to GND or use a pull-up resistor to connect it to the V_{DD} potential.

6 Sensor Communication

6.1 Command Overview

Command	Description
0x2C1B	Measurement, single shot, I^2C clock stretching enabled; Use current resolution
0x241D	Measurement, single shot, I^2C clock stretching disabled; Use current resolution
0x201E	Measurement, periodic; Use current resolution and interval
0xE000	Fetch periodic measurement data
0x30A2	Soft Reset
0x3093	Break (end periodic measurement)
0x3041	Clear Status Register 1
0xF32D	Readout of Status Register 1
0xF352	Readout of Status Register 2
0x7029	Read Identification
0x72A7	Read / Write Sensor Settings (RAM)
0x06	I^2C Reset at general call address 0x0

Table 10: TEE501 commands

6.2 Measured Data Format

Temperature [°C] = (Temperature MSB x 256 + Temperature LSB) /100

6.3 Measurement Modes

There are two different operation modes to communicate with the sensor:

1. Single Shot Measurement

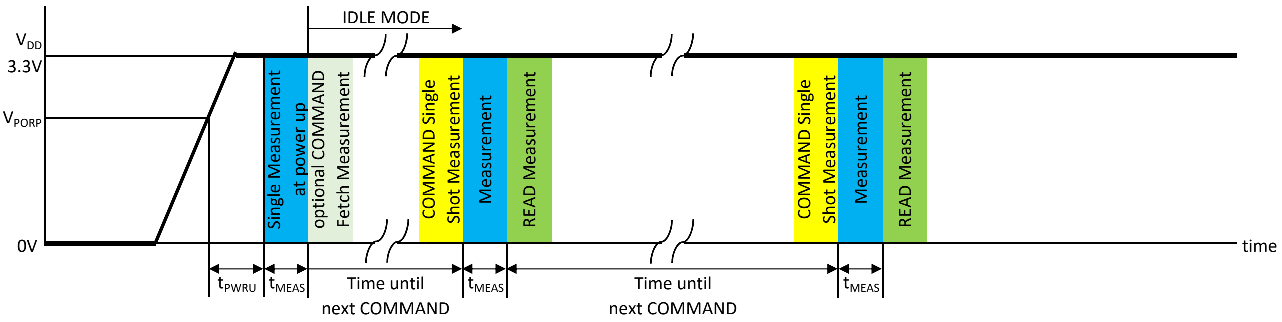

Figure 6: Single shot measurement

2. Periodic Measurement

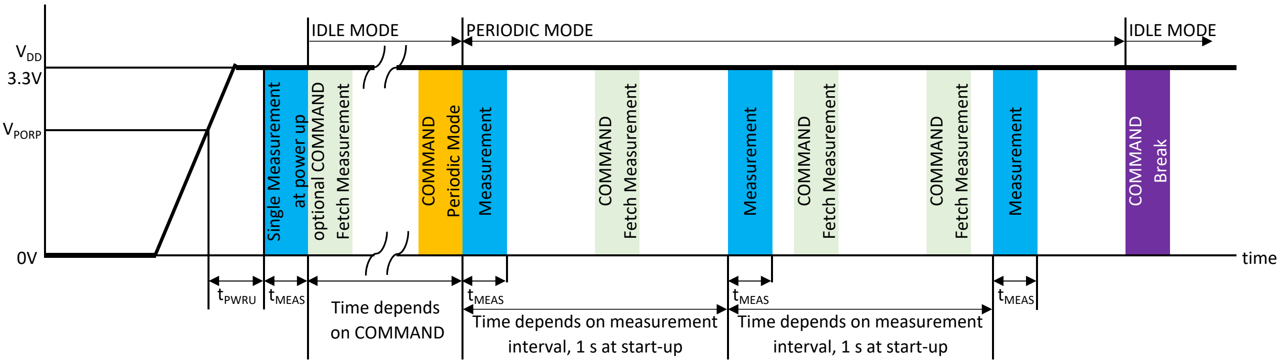

Figure 7: Periodic measurement

6.4 Single Shot Measurement (0x2C1B, 0x241D)

The command initiates a single measurement, the measured data is available for query after t_{MEAS}. I^2C clock stretching enabled: waiting for the end of the measurement during command execution.

Condition	CMD Hex Code	
I^2C clock stretching	**MSB**	**LSB**
Enabled	2C	1B
Disabled	24	1D

Table 11: Single shot measurement with or without clock stretching

A single-shot measurement is started after the command has been received successfully. The readout of the calculated T value is started by sending the I^2C address again in read mode:

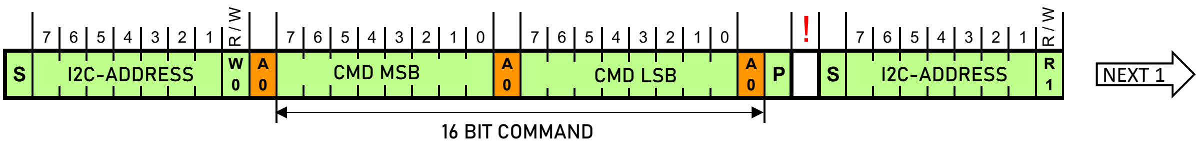

Figure 8: Start single shot measurement readout

In case a command with clock stretching enabled has been issued, the slave holds SCL low until the calculation has been finished:

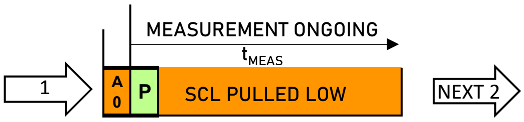

Figure 9: Clock stretching during measurement

In case a command without clock stretching has been issued, the slave does not acknowledge (NACK) a read header as long as the calculation has not been finished:

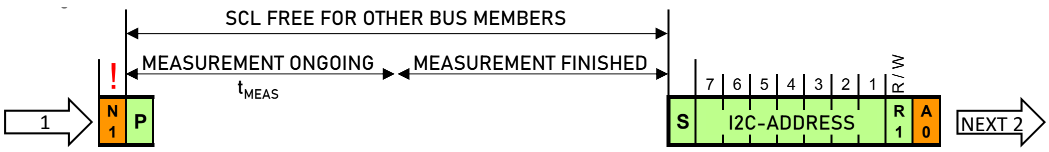

Figure 10: Poll for meauring values until ACK

After the calculation is finished, the slave responds to a read header with a pair of data words, each of them is followed by an 8 bit checksum (CRC8). The data word contains the temperature value. The master has to acknowledge each single data byte by an acknowledge (ACK), otherwise the slave will stop sending any further data and wait for a stop condition (P):

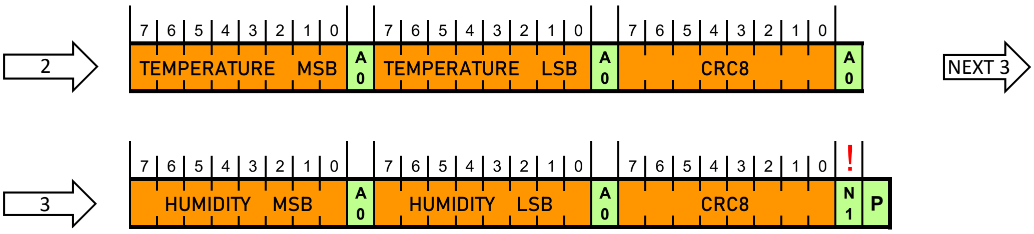

Figure 11: Measured value readout

Data Bit From Master to Slave
Data Bit From Slave to Master

! = Note the deviation!

S = Start condition
P = Stop condition

R = Read Bit
W = Write Bit

A = Acknowledge (SDA low)
N = Not Acknowledge (SDA high)

6.5 Periodic Measurement (0x201E)

Once issued, measurements and calculations are started automatically with a given measuring interval and resolution. The standard measurement interval is 1s and the T resolution is 13 bit. If necessary, the measurement frequency and the measurement resolution can be changed (see chapter 6.13 Change Sensor Settings).
This mode does not support clock stretching.

Command	CMD Hex Code
Periodic measurement	201E

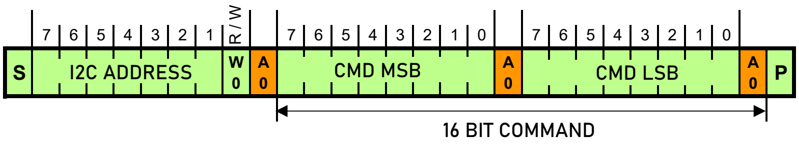

Figure 12: Periodic measurement commands

A periodic measurement command with a different measurement interval / resolution can be issued at any time, but the calculated value will be updated according the new settings earliest after a measurement with the new settings has been performed. Please refer to chapter 6.13 Change Sensor Settings.

6.6 Fetch Periodic T Measurement Results (0xE000)

Readout of calculation results in periodic measurement mode can be performed using the fetch command. This is similar to the readout of measurement results in single-shot mode, except that clock stretching is always disabled. The slave will answer with NACK if no measurement results are available.

Command	CMD Hex Code
Fetch data	E000

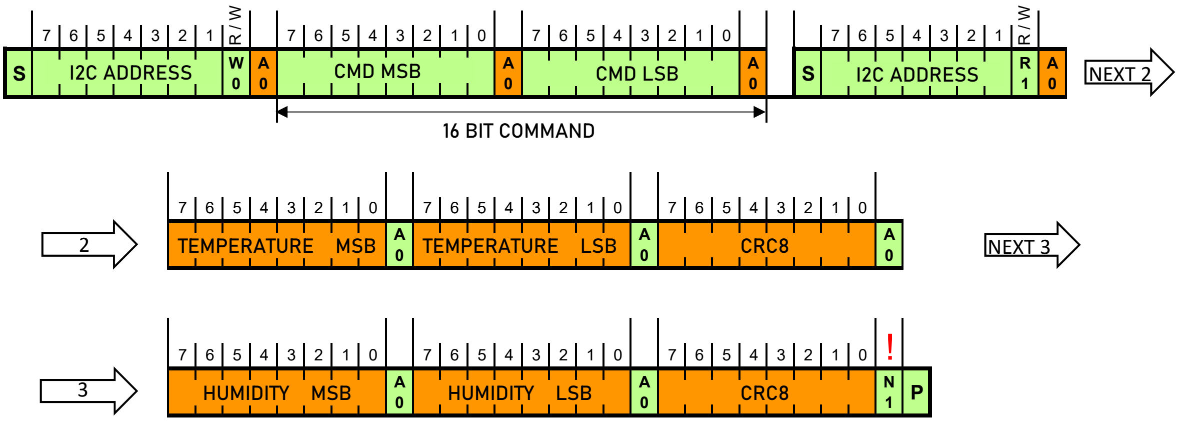

Figure 13: Fetch command

This command is also suitable for reading out the measured data generated by the power-up procedure.

6.7 Break Command (0x3093)

The periodic measurement mode can be stopped using the break command. After finishing an ongoing measurement, the sensor will enter the idle mode. An ongoing measurement can delay the transition into the idle mode.

Command	CMD Hex Code
Break	3093

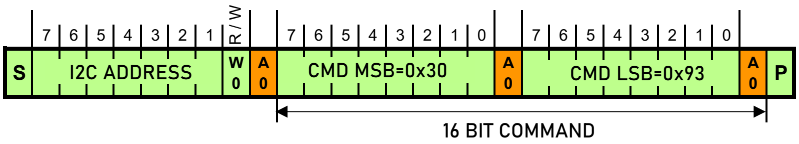

Figure 14: Break command

A single measurement (command) or a reset (command or power-up) both stop the periodic measurement, too.

6.8 Reset Commands (0x30A2, 0x06)

The slave supports multiple commands to reset the device. Once a reset command is received, the device is completely reset, like a reset during power-up. During the reset time, the device will not respond to any request on the I^{2}C interface. In order to execute the reset on a specific device, the command “Soft Reset” can be used. This forces the system to execute the startup procedure without the need to remove the power supply.

Command	CMD Hex Code
Soft reset	30A2

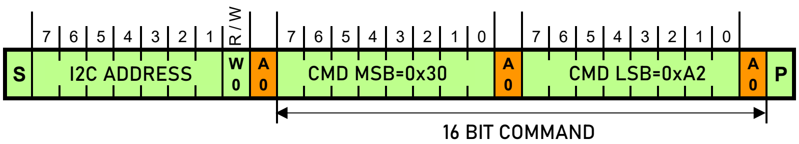

Figure 15: Soft reset

In order to reset all devices on the bus, the master can use the “General call” mode. This generates a reset (system startup) in all devices on the bus which support this function. The effect is the same as for the “Soft Reset” command.

Command	CMD Hex Code
Address byte	00
Second byte	06

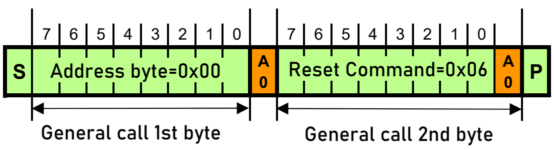

Figure 16: Reset through general call

In order to reset the I^{2}C interface only, keep SDA high while toggling SCL nine times or more. This must be followed by a start condition preceding the next command. This sequence does not affect any configuration, status register or system status.

6.9 Status Register (0xF32D, 0xF352, 0x3041)

The sensor implements two 16 bit status registers.
Its contents can be read using the following command:

Command	CMD Hex Code	
	MSB	LSB
Read out Status Register 1	0xF3	0x2D
Read out Status Register 2		0x52

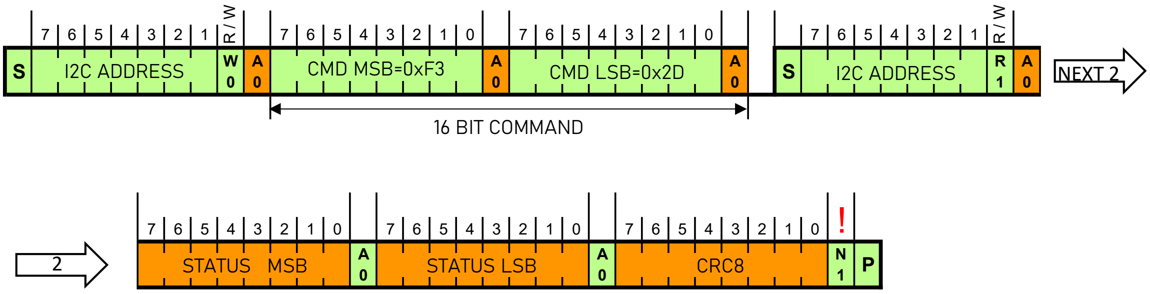

Figure 17: Read out status register

Upon receipt of the following clear command, bits 15, 4 and 3 are cleared in the status register. All other bits remain unaffected:

Command	CMD Hex Code
Clear Status Register	3041

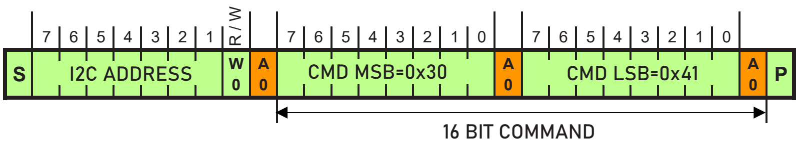

Figure 18: Clear status register 1

PLEASE NOTE

The Status Register 2 is read only!

Bit	Name	Description
15	OVERALL_ERROR	0: none of bits [11:0] set 1: at least one of bits [11:0] set This bit is cleared upon the Clear Status Register command
14	Reserved	-
13	Reserved	-
12	Reserved	-
11	Reserved	-
10	Reserved	-
9	Reserved	-
8	Reserved	-
7	Reserved	-
6	Reserved	-
5	Reserved	
4	System Reset	0: no reset since status 1 clear 1: POR or I^2C reset This bit is cleared upon the Clear Status Register command
3	POR	0: no POR since status 1 clear 1: POR occurred This bit is cleared upon the Clear Status Register command
2	Reserved	-
1	Reserved	-
0	CRC	1: checksum of the latest write transfer failed

Table 12: Status register 1

Bit	Name	Description
15	NEW_MEAS	New T measurement since last readout available
14	NEW_T_MEAS	New T value since last readout available Cleared upon start of T readout
13	Reserved	-
12	Reserved	-
11	Reserved	-
10	PERIODIC_MODE	Status of cyclic measurement 0: only measurements on demand 1: periodic mode active
9	Reserved	-
8	Reserved	-
7	Reserved	-
6	Reserved	-
5	Reserved	-
4	Reserved	-
3	Reserved	-
2	Reserved	-
1	Reserved	-
0	T_VALID	0: T measurement faulty 1: T measurement OK

Table 13: Status register 2

6.10 Read Identification (0x7029)

Each sensor device has a specific 8-byte identification. This Identification allows a factory backtracking of each device. When the following command is issued, the I^2C slave sends all 8 bytes consecutively, followed by a CRC8 checksum (see chapter 6.12 CRC Calculation).

Command	CMD Hex Code
Read Identification	7029

PLEASE NOTE

During the I^2C communication before the I^2C address read, a repeated start sequence must be executed, the sequence "stop + start" is not sufficient.

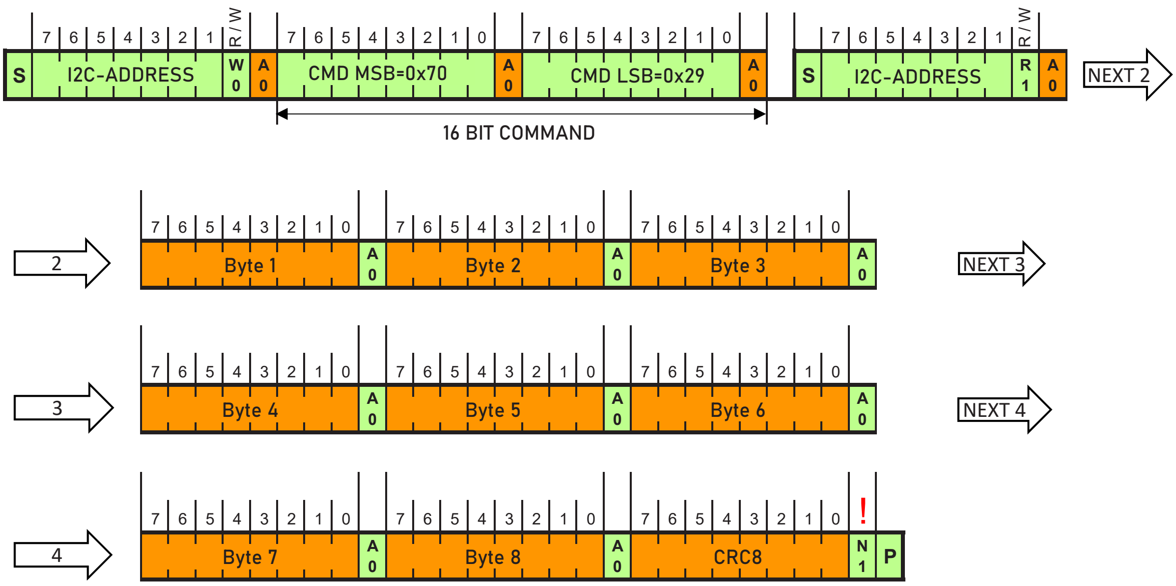

Figure 19: Read Identification

Example:
"1C4606026156553C" (Hexadecimal)

6.11 Change Sensor Settings (0x72A7)

This command allows to change the sensor's settings. They stay in place until any reset. Sensor settings can only be changed in idle mode.

Command	CMD Hex Code
Change Sensor Settings	72A7

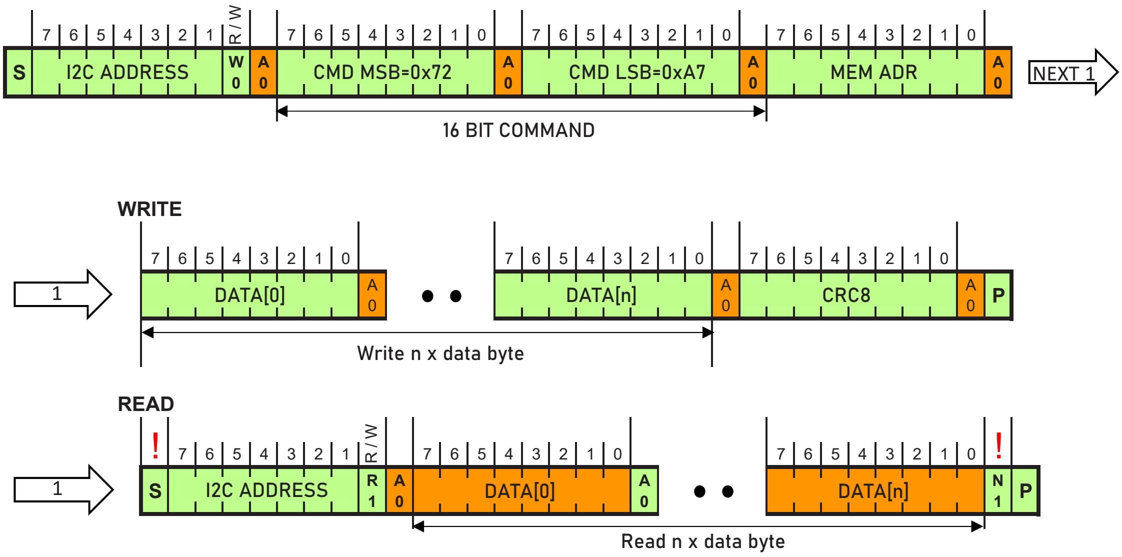

Figure 20: Memory access

Address	Function	Default Value	bit	Name	R/W	Description
0x0F	Measurement resolution	0x2D (0010 1101) T = 13 bit	7:0	T_RES	R/W	0x00: 8 bit 0x01: 9 bit 0x02: 10 bit 0x03: 11 bit 0x04: 12 bit 0x05: 13 bit 0x06, 0x07: 14 bit Others: reserved
0x10 0x11	Measurement interval in periodic mode	0x0014 1 second	15:0	RM_CYCLE	R/W	Measurement cycle in run- mode. Unit of an LSB is 1/20 s (50 ms), RM_CYCLE ranges from 0 (start immediately after calculation is done) to 0xffff * 0.05 s = 54 m 36.75 s

Table 14: Sensor settings registers

PLEASE NOTE

A short measurement interval can influence the power consumption and therefore the self-heating of the sensor.

PLEASE NOTE

The CRC8 calculation includes all bytes following the command bytes.

6.12 CRC Calculation

Response data words/memory write data are protected by a CRC8 checksum:

Property	Value
Name	CRC8
Width	8 bit
Polynomial	0x31 (x8 + x5 + x4 + 1)
XOR input	0xFF
Reflect input	False
Reflect output	False
XOR output	0x00

Table 15: CRC checksum properties

6.13 Package / Dimensions

The TEE501 sensor is provided as a DFN (= Dual Flat No Leads) package.

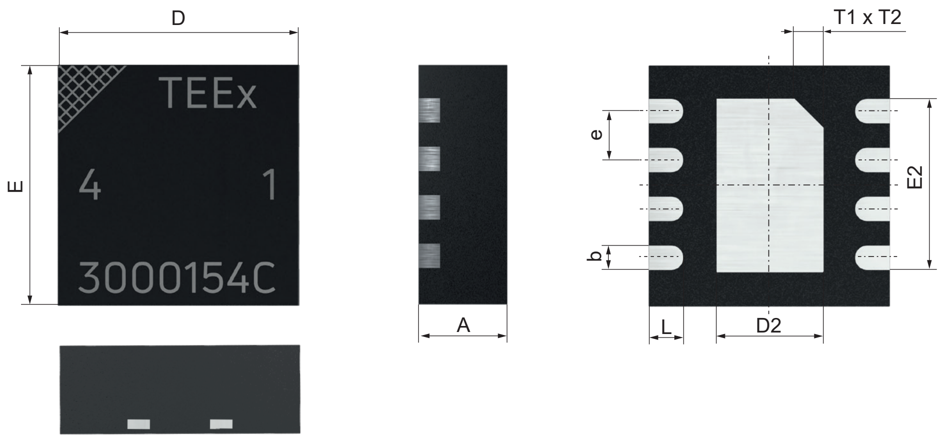

Figure 21: Package layout

PARAMETER	SYMBOL	MIN.	NOM.	MAX.	UNIT	COMMENT
Package width	D	2.40	2.50	2.60	mm	
Package length	E	2.40	2.50	2.60	mm	
Package height	A	0.80	0.90	1.00	mm	
Leadframe height	A3		0.20		mm	Not shown in the drawing
Pad pitch	e		0.50		mm	
Pad width	b	0.20	0.25	0.30	mm	
Pad length	L	0.30	0.35	0.40	mm	
Thermal pad length	D2	1.00	1.10	1.20	mm	
Thermal pad width	E2	1.70	1.80	1.90	mm	
Thermal pad marking	T1xT2		0.30x0.30		mm	Indicates pin 1

Table 16: Package dimensions

6.14 Tape and Reel Packaging

The TEE501 has a Moisture Sensitivity Level (MSL) of 1, according to IPC/JEDEC J-STD-020.
It is recommended to further process the sensors within 1 year after date of delivery.

Dimensions T&R in mm:

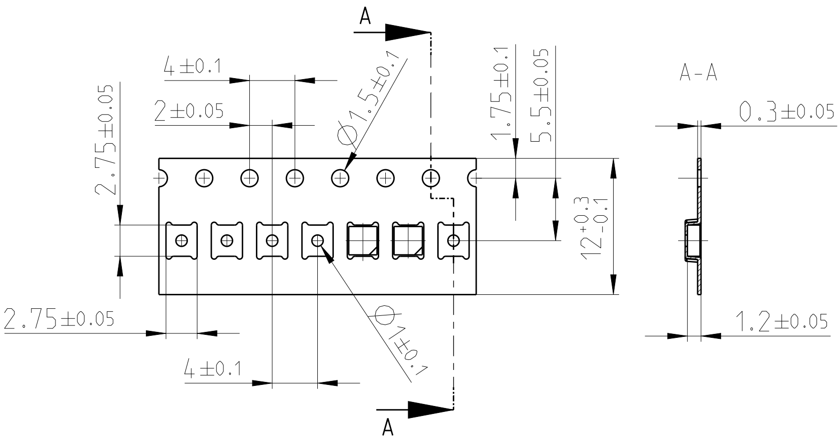

Figure 22: Tape layout

Reel size 330.2 mm (13"), Leader 520 mm (20.5"), Trailer 1 240 mm (48.8").

Orientation on the tape:

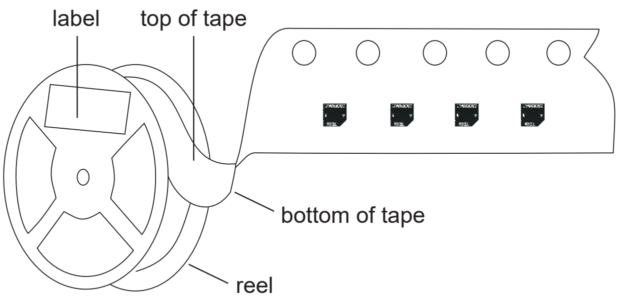

Figure 23: Orientation on the tape

6.15 Traceability

There are two possibilities for identification / traceability:

1. Read identification command (0x7029):
   serial number of each individual sensor (see description of command 0x7029)
2. Laser marking:

A triangular mark at the top left indicates pin 1.

The upper line represents the designation of the component and consists of up to 6 characters. The “x” is a placeholder for the exact type, e.g. 501.

The remaining characters are a tracking code and are used by the manufacturer for identification.

Figure 24: TEEx laser marking

6.16 Ordering Information

Feature	Description	Code
		TEE501-
Tape and reel packaging	2 500 pcs. per reel	TR2,5

Ordering example: **TEE501-TR2,5**

Feature	Code	Description
Model	TEE501	Digital Temperature Sensor
Tape and reel packaging	TR2,5	2 500 pcs. per reel

6.17 Recommended Layout

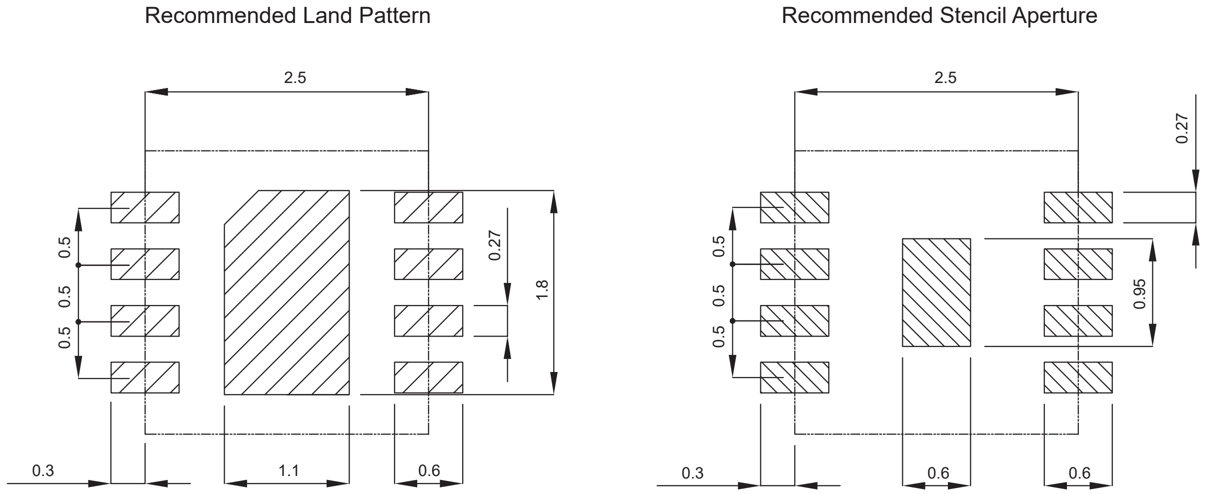

Figure 25: Recommended land pattern and stencil aperture

7 Quality

The TEE501 is qualified for automotive applications according to AEC-Q100 grade 1 with an extended operating temperature range of +135 °C. In addition, the TEE501 is qualified for industrial and commercial operating environments according to JEDEC JESD47.

8 Additional Documentation

Document	Description	Link
TEE501 Handling Instructions	TEE501	www.epluse.com/tee501
TEE501 CRC8 Code Example	Code samples for Arduino and Raspberry PI	https://github.com/EplusE

Table 17: Applicable documentation

9 Revision History

Date	Version	Page(s)	Changes
March 2022	1.0	1-21	Initial release
May 2022	1.4	1-21	Editorial changes
August 2022	1.5	1-23	Editorial changes
December 2022	1.6	1-23	Chapter 6.14, Fig. 23 and 24: ASIC orientation on tape corrected Chapter 6.16 Ordering Information updated Link to NXP's UM10204 updated and hint added
June 2023	1.4	1 23	Typical Applications: Automotive Industry added Chapter 7: Text on standards improved.
July 2023	1.5	1-25	New layout

Table 18: Revision history

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