

Fully Calibrated Temperature Sensor IC

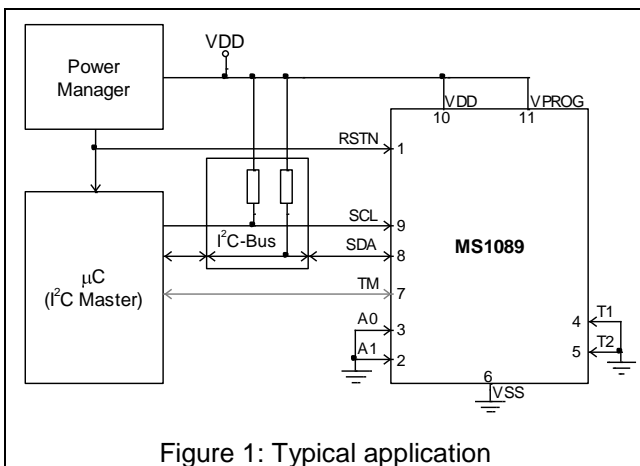
1 General Description

The integrated circuit MS1089 is a fully integrated calibrated digital low power temperature sensor with a typical temperature measurement accuracy of $\pm 0.3^{\circ}\text{C}$. The MS1089 has an I²C interface and is available in Chip-Scale-Package (CSP).

2 Applications

- Wireless sensor tags and cards
- Wearables
- Power-supply temperature monitoring
- Environmental monitoring and HVAC
- Computer peripheral thermal protection
- Notebook computers
- Phone batteries
- Battery management
- Thermostat controls

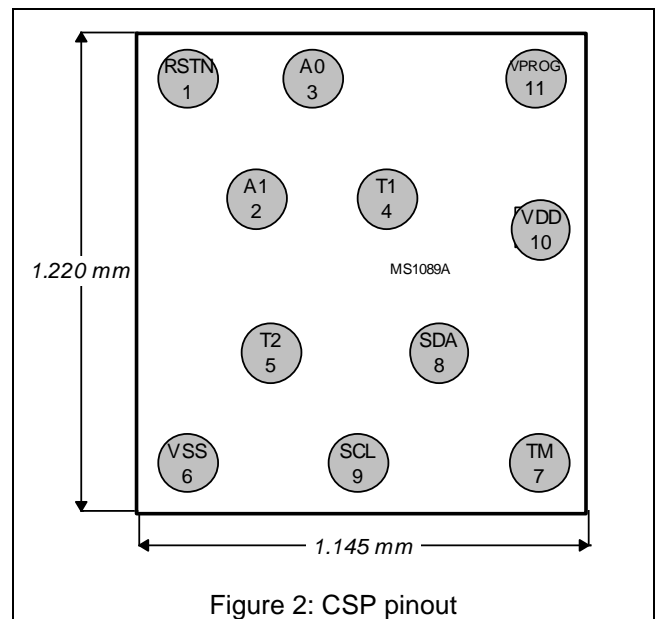
3 Typical application



4 Features

- Serial 2-wire I²C Fast-mode Plus (1MHz) interface
- Up to 4 sensors can be addressed over the same serial bus (4 sub-addresses)
- Reset either via input pin or via I²C command
- Hardware handshake to start a temperature measurement and wake-up the microcontroller at the end
- High accuracy: $\pm 0.3^{\circ}\text{C}$ from $+0^{\circ}\text{C}$ to $+60^{\circ}\text{C}$
- Three resolutions: 0.1°C (11-bit), 0.05°C (12-bit) and 0.025°C (13-bit), selectable with I²C
- Fast measurement time: 30ms typical at 0.1°C resolution
- Ultra-low current in sleep mode: only leakage
- Peak current during measurement: $70\ \mu\text{A}$
- Avg. current: $28\ \text{nA}$ at 1 measurement per minute
- Supply range: 1.8V to 3.6V
- Available in chip-scale package (CSP)

5 Pinout



6 Ordering Information

Table 1: Ordering information

Type	Package	Shipping	Article No.
MS1089	CSP	Tape&Reel	9160469

7 Pin description

Table 2: Pin description

Pin	Symbol	I/O ⁽¹⁾	Description
1	RSTN	I	Reset input with internal pull-up (active LOW) ⁽²⁾
2	A1	I	User-defined I ² C sub-address bit 1
3	A0	I	User-defined I ² C sub-address bit 0
4	T1	I	Reserved input. Must be connected to VSS
5	T2	I	Reserved input. Must be connected to VSS
6	VSS	S	Ground
7	TM	I/O	Temperature Measurement pin with Hardware Handshake; open-drain with internal pull-up ⁽³⁾
8	SDA	I/O	I ² C-bus serial bidirectional data line; open-drain
9	SCL	I	I ² C-bus serial clock input
10	VDD	S	Positive supply voltage
11	VPROG	I	Reserved input. Must be connected to VDD

Notes:

1. I: Input, O: Output, S: Supply
2. If pin RSTN is not used, it can be either not connected or connected to VDD
3. If pin TM is not used, it must be not connected, to prevent unnecessary power consumption during operation

8 Functional Description

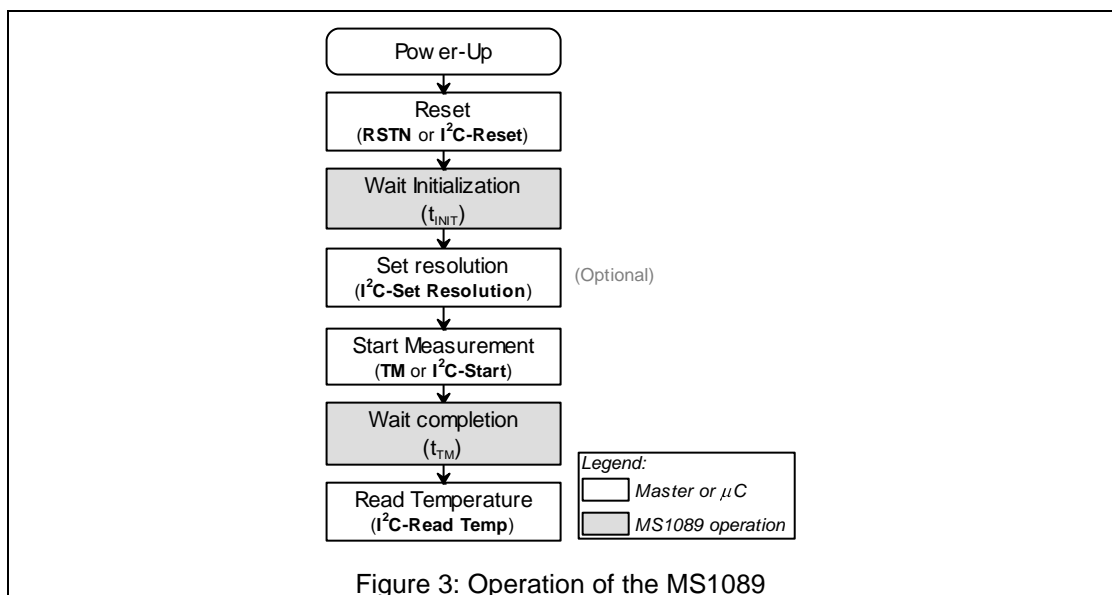


Figure 3: Operation of the MS1089

8.1 Power-Up

After power up, the MS1089 must be initialized with a Reset. A Reset can either be done by setting input RSTN LOW or by software with the I²C Reset command. It is strongly advised to use the RSTN pin after power-up to correctly initialize the MS1089.

Important:

1. If not initialized with a Reset, the thermometer of the MS1089 is not calibrated and its accuracy is not guaranteed.
2. After power-up and until a Reset is applied, the current consumption is not specified. In the worst case it can be the sum of the operating current during a temperature measurement (I_{DD} - see Table 9: DC characteristics) with the current during initialization ($I_{DD:INIT}$).

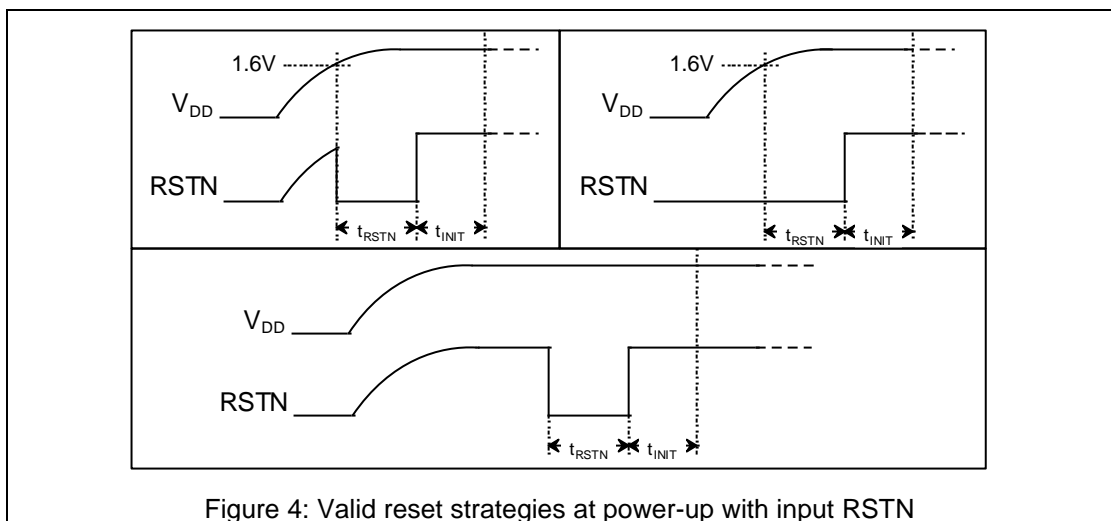
8.2 Initialization of the MS1089

After a Reset pulse on RSTN or an I²C Reset-command, the MS1089 performs an initialization procedure to calibrate the thermometer. During that procedure, which has a duration of t_{INIT} (section 10.3), the power consumption is $I_{DD:INIT}$ (section 10.2).

During initialization the MS1089 will acknowledge I²C commands. It is advisable however not to issue any command other than *Set measurement resolution I3* (Table 7: I²C command table) until initialization is complete.

After initialization, the temperature measurement resolution is set to 0.1°C (11-bit) and the MS1089 is on an ultra-low power state (only leakage current flows).

8.3 Reset and initialization with Input RSTN



Notes:

1. Pin RSTN has an internal pull-up (R_{PU} , see Table 9: DC characteristics) and can be driven by an open-drain driver or an RC filter.
2. If pin RSTN is not used in the application (I²C-Reset is used to reset the MS1089), it can be either unconnected or connected to the positive power supply

8.4 Reset and initialization with I²C

If the pin RSTN cannot be used to initialize the MS1089 after power-up, the I²C command *Chip reset* I4 (Table 7: I²C command table) shall be used for that purpose. To ensure that after power-up the I²C circuitry is in a defined state, it is advisable to do one of the next two operations before using the I²C command I4:

1. Clock SCL for 20 to 30 times while SDA remains HIGH (Figure 5).
2. Send a *General Call* I²C command¹ (I²C-address 00h) (Figure 6).

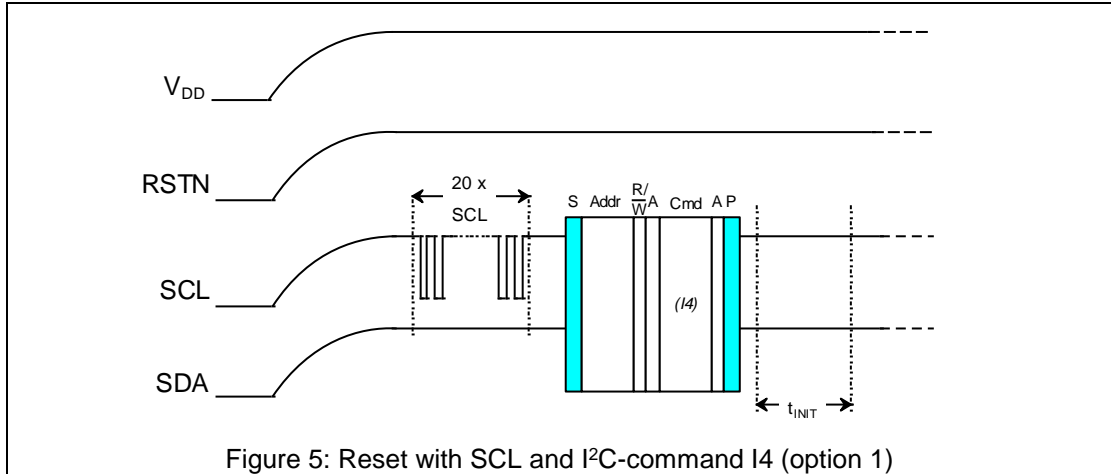


Figure 5: Reset with SCL and I²C-command I4 (option 1)

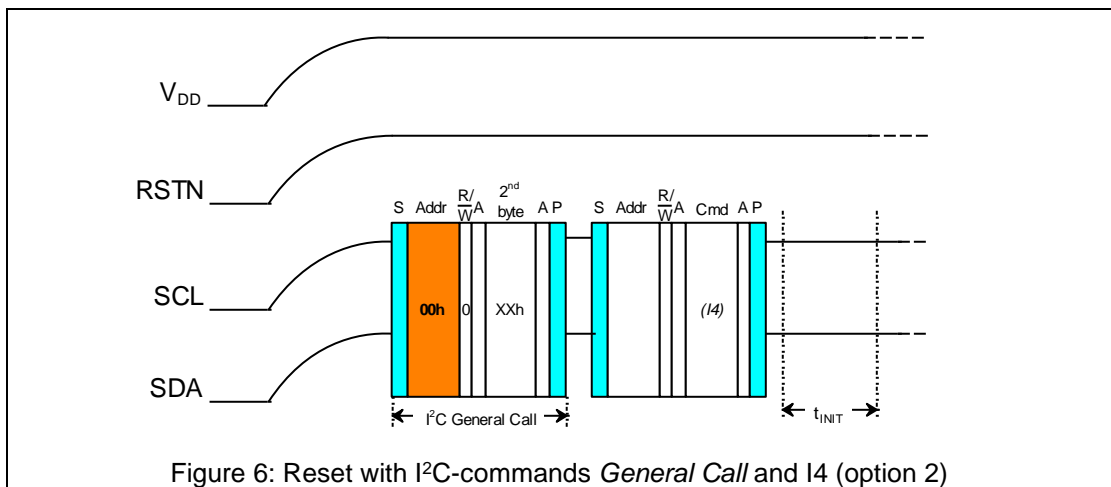


Figure 6: Reset with I²C-commands *General Call* and I4 (option 2)

After sending the I4 (I²C-Reset) command the MS1089 initializes the calibration of the thermometer. After t_{INIT} , it is ready for operation.

8.5 Setting the resolution of the Thermometer

The MS1089 offers 3 selectable resolutions: 0.1°C (11-bit), 0.05°C (12-bit) and 0.025°C (13-bit). After Reset and initialization, the temperature measurement resolution of the MS1089 is set to 0.1°C (11-bit). To select a different resolution the master must send the I²C *Set measurement resolution* (I3) command (Table 7: I²C command table) to the MS1089.

¹ The MS1089 never acknowledges the general call command, therefore the 2nd byte can be any value.

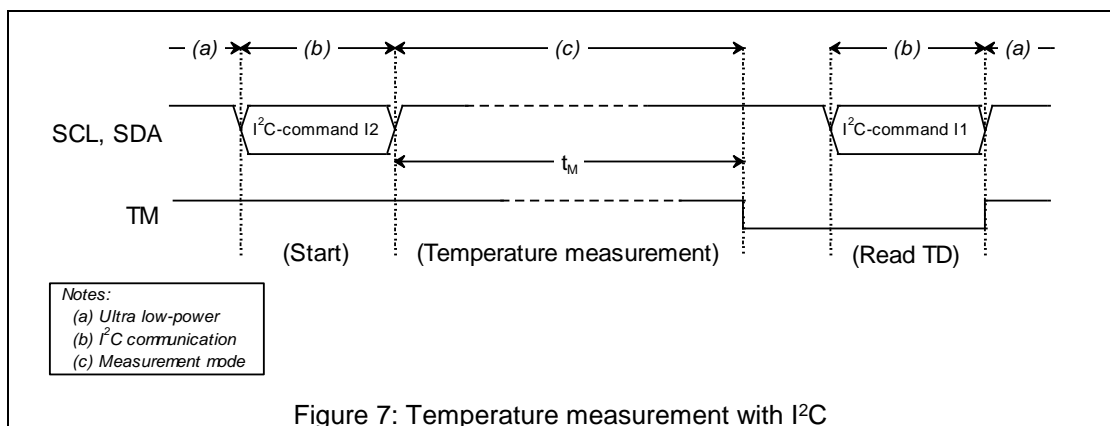
Notes:

1. The resolution of the thermometer can be only set while the thermometer is idle. During initialization or while a temperature measurement is ongoing, any request for setting the resolution is ignored
2. The format of the I²C-Read temperature data TD (Table 3: Data format temperature digital value (TD)) is the same for all 3 resolutions
3. The time required for a temperature measurement to complete, t_M (Table 10: AC characteristics) is dependent on the selected resolution. Consequently it also has an impact on the average current consumption $I_{DD:AV}$ (Table 9: DC characteristics)

Important: The measurement resolution is not stored in non-volatile memory. After a Power-Up or a Reset, it must always be set using I²C.

8.6 Temperature measurement with I²C

After initialization, the MS1089 is in ultra-low power mode and ready for operation. A temperature measurement can be initiated using the I²C *Start temperature measurement* command I2 (Table 7: I²C command table). At the end of the measurement the MS1089 indicates this to the I²C-master by pulling TM LOW¹. The digital value of the temperature is available on the internal register TD (Table 3: Data format temperature digital value (TD)) and can be read with the I²C *Read Temperature value TD* command I1. Upon receiving the I1 command, the MS1089 releases the TM pin.



Notes:

1. If a new I²C *Start temperature measurement* command (I2) is sent while a temperature measurement is on-going, the MS1089 generates no acknowledge and the command is ignored
2. If an I²C *Read temperature value TD* command (I1) is sent while a temperature measurement is on-going, the MS1089 returns the value TD=0 (-80.000°C)
3. After a temperature measurement, it is not mandatory to read the value of TD with the command I1 before sending another *Start temperature measurement* command. If a second I²C command I2 is sent and TM is still low, TM is released and a new measurement is started
4. During a temperature measurement (depicted as (c) in the previous figure) the master shall not pull-down input TM. If the master pulls down TM before the MS1089

¹ To avoid unnecessary power consumption, the MS1089 disables the internal pull-up on pin TM while pulling TM LOW.

has finished the temperature measurement, the MS1089 will not pull-down TM once the measurement is complete and will not acknowledge any further I²C command until a RESET happens (with pin RSTN or I²C-command I4).

8.7 Temperature measurement with pin TM (hardware handshake)

In addition to starting a measurement using the I²C command I2, a temperature measurement can be initiated by using pin TM. A handshake protocol allows starting a measurement and detecting when it is complete, for example using TM as a wake-up interrupt.

To start a measurement the master must force TM LOW and then release it. During the measurement, pin TM is set HIGH again by the internal pull-up of the MS1089. When the measurement is complete the MS1089 indicates this by forcing TM LOW. This can be used by the master e.g. as a wake-up interrupt to read the temperature value TD. The MS1089 keeps TM LOW until the master reads TD using the I²C command I1.

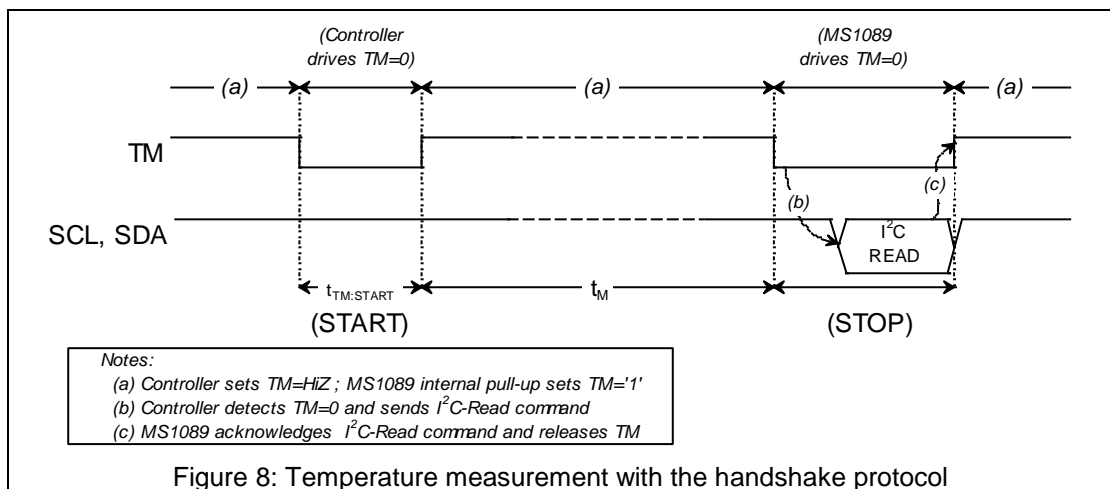


Figure 8: Temperature measurement with the handshake protocol

Notes:

1. During the TM start pulse ($t_{TM:START}$ in Figure 8) current flows through the internal pull-up of pin TM. During the TM stop-pulse however, the MS1089 switches off its internal pull-up and so saves power consumption.
2. If the controller generates a new LOW pulse on TM before the temperature measurement is complete, the MS1089 will not pull down TM once the measurement is complete and will not acknowledge any further I²C command until a RESET happens (with pin RSTN or I²C-command I4).
3. If the controller initiates a new temperature measurement with a TM pulse while the MS1089 is still pulling it LOW, that pulse is ignored. The controller must first send a valid I²C command (for example, the I²C *Read temperature value TD* command I1) to make the MS1089 release TM, before generating a new TM pulse.
4. If two or more MS1089 are used in the application (for example when measuring the temperature in 2 places - see Figure 9), the controller can start both MS1089 simultaneously by pulling down all TM inputs at the same time. In contrast, starting with I²C requires sending two I2 commands sequentially, one per MS1089 chip.

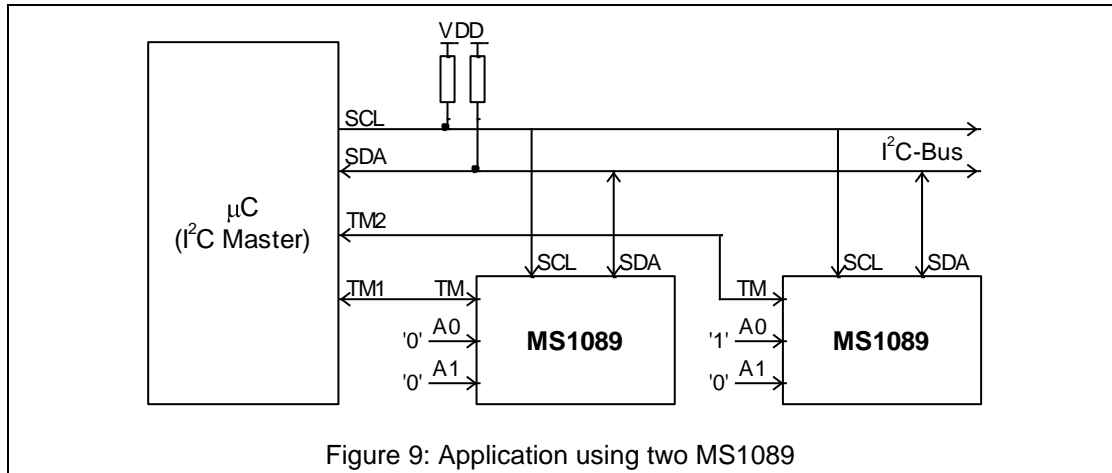


Figure 9: Application using two MS1089

8.8 Temperature data format

Table 3: Data format temperature digital value (TD)

Byte 1							Byte 0								
D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
0	0	0	TD12 (MSB)	TD11	TD10	TD9	TD8	TD7	TD6	TD5	TD4	TD3	TD2	TD1	TD0 (LSB)

The digital temperature value TD is placed in the lowest 13 bits (D12..D0) of the 2 data bytes returned by command I1. Bits D15..D13 are always 0. The digital temperature value can be converted to degree Celsius or Fahrenheit with the following formulas:

$$T (^{\circ}\text{C}) = \frac{\text{TD}}{40} - 80$$

$$T (^{\circ}\text{F}) = \left(\frac{\text{TD}}{40} - 80\right) \times 1.8 + 32$$

Table 4: Example of results of the same temperature measurement using different resolutions

Resolution	TD (binary)		TD (decimal)	TA [°C]
	Byte 1	Byte 0		
13-bit	0001 0000	0000 0011	4099	22.475
12-bit	0001 0000	0000 001 0	4098	22.45
11-bit	0001 0000	0000 000 0	4096	22.4

Notes:

1. Digits in bold are always 0, regardless of the temperature
2. Both conversion formulas above are valid for all 3 resolutions.
3. In 12-bit resolution the value of TD is always multiple of 2 (i.e. D0 is always 0) and in 11-bit a multiple of 4 (i.e. both D1 and D0 are always 0).

9 I²C interface

The MS1089 has a slave receiver/transmitter I²C interface compatible with 1MHz SCL frequency. Pin SCL is clock and pin SDA is data input/output.

Both pins SDA and SCL are not electrically connected to the internal supply voltage of the MS1089. Their V_{OH} level can therefore be different than V_{DD}. For example, if V_{DD} of the

MS1089 is 1.8V, the pull-ups of SDA and SCL can still be connected to a different voltage like 3.6V, provided the limiting values are not exceeded (Table 8: Limiting values and ESD Protection).

Note: SCL clock stretching is not implemented.

9.1 I²C address

The 7-bit I²C slave address of the MS1089 consists of five defined bits A6 to A2 and two selectable bits A1 and A0, defined by the digital inputs A1 and A0. This allows independent operation of up to four MS1089 on the same I²C bus.

Table 5: I²C slave address of MS1089

Bit	A6	A5	A4	A3	A2	A1	A0	R/W
	1	0	0	0	1	A1	A0	R/W

Note: A1 and A0 must be electrically either connected to VDD, VSS or driven by another circuit. They must not remain floating.

9.2 I²C protocol

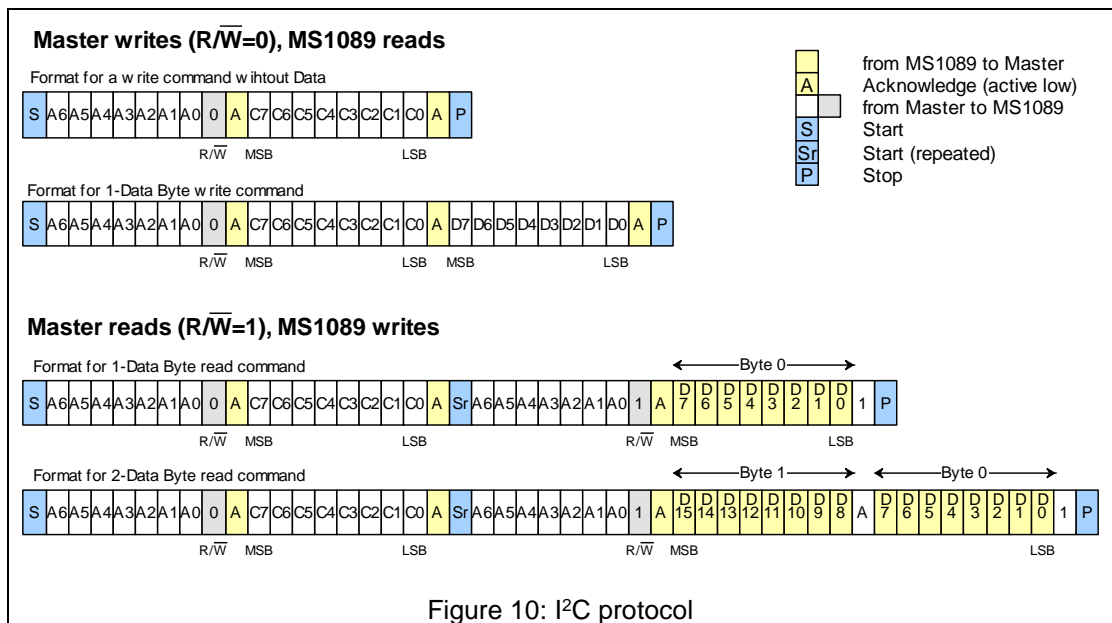


Figure 10: I²C protocol

9.3 I²C commands

Table 6: I²C command byte

Bit	C7	C6	C5	C4	C3	C2	C1	C0
	0	0	0	0	0	0	C1	C0

Table 7: I²C command table

Command	C1	C0	R/W	Type	Data D15=MSB, D0=LSB	Description
I1	0	0	1	2-Byte	TD = D15..D0	Read temperature value TD
I2	0	1	0	0-Byte	-	Start temperature measurement
I3	1	0	0	1-Byte	D1 D0=00 (11-bit) D1 D0=01 (12-bit) D1 D0=1X (13-bit)	Set measurement resolution
			1	1-Byte	Res = D1 D0	Read measurement resolution (note 2)
I4	1	1	0	0-Byte	-	Chip reset

Notes:

1. Bits C7 to C2 must always be 0. Sending commands with any of these bits set to 1 can lead to malfunction of the MS1089.
2. While reading the resolution only bits D1 and D0 are significant; D2 to D7 are don't-care and can have any value. It is advised to perform a AND of the outcome of the I²C read command I3 with the mask 0x03 to determine the resolution.

9.4 I²C communication examples

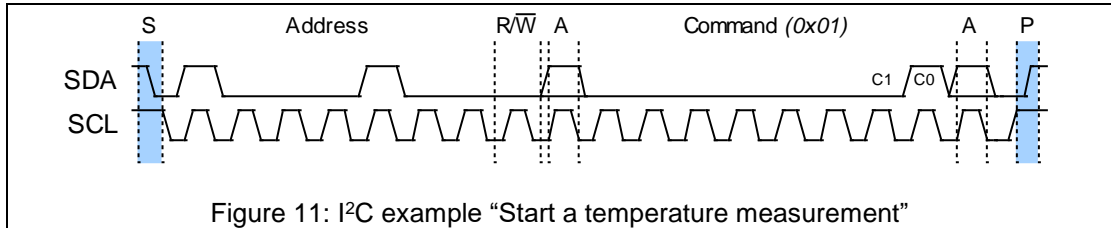


Figure 11: I²C example "Start a temperature measurement"

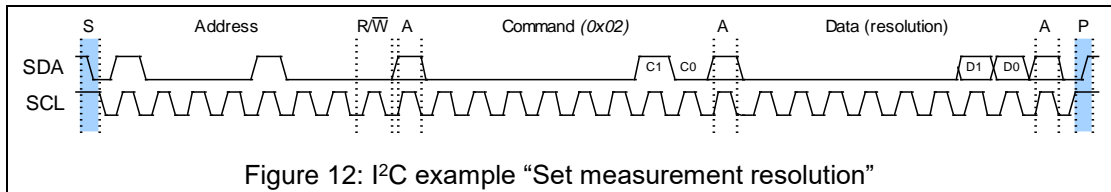


Figure 12: I²C example "Set measurement resolution"

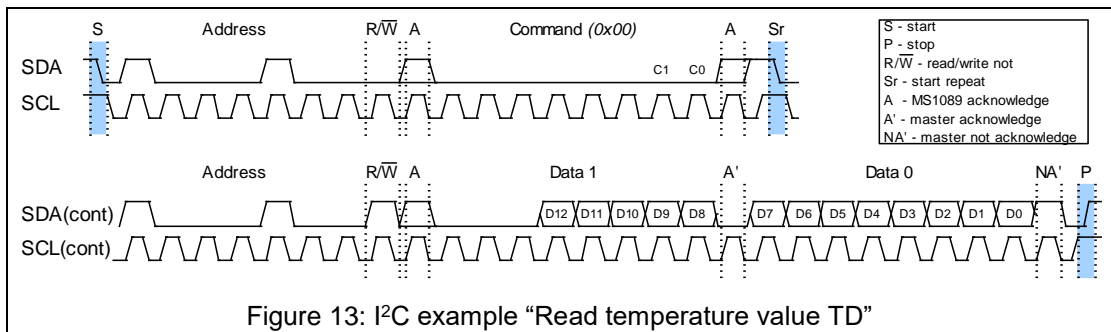


Figure 13: I²C example "Read temperature value TD"

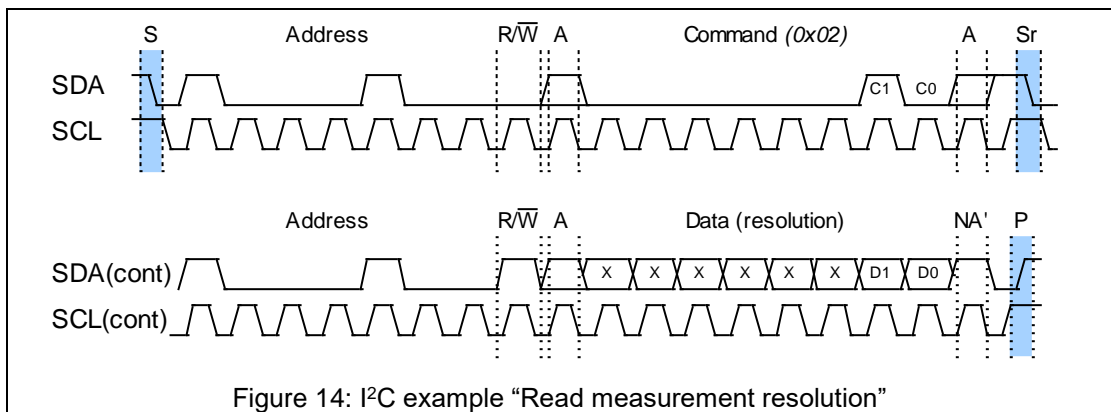


Figure 14: I²C example "Read measurement resolution"

10 Characteristics

10.1 Limiting values and ESD protection

Table 8: Limiting values¹ and ESD Protection²

Name	Parameter	Min	Max	Unit
V _{DD}	Positive supply voltage wrt to V _{SS}	-0.5	3.6	V
V _I	Input voltages wrt to V _{SS} (digital inputs)	-0.5	V _{DD} +0.5	V
	Input voltages wrt to V _{SS} (SDA, SCL)	-0.5	3.6	V
I _I , I _O	Input and output currents	-10	10	mA
I _{VSS}	Total current to V _{SS}	-25	25	mA
P _{TOT}	Power dissipation		300	mW
T _{stg}	Storage temperature	-60	+125	°C
T _J	Junction temperature		+125	°C
V _{ESD}	Electrostatic discharge voltage HBM		+/- 2000	V

¹ These are stress ratings only. Stress above one or more of the limiting values may cause permanent damage to the device. Operation of the device at these or at any other conditions above those given in the characteristics section of the specification is not implied. Exposure to limiting values for extended periods may affect device reliability.

² Inputs and outputs are protected against electrostatic discharge during normal handling. However, to be totally safe, it is advisable to undertake precautions appropriate to handling MOS devices.

10.2 DC Characteristics

 Table 9: DC characteristics
 Conditions: $V_{DD} = 2.2V$, $T = 25^{\circ}C$; unless otherwise specified

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{DD}	Positive supply voltage		1.8	2.2	3.6	V
I_{DD}	Operating current	Stand-by		4		nA
		Temperature measurement	60	70	90	μA
$I_{DD:AV}$	Average operating current	11-bit ($0.1^{\circ}C$), note 1		27		nA
		12-bit ($0.05^{\circ}C$), note 1		55		
		13-bit ($0.025^{\circ}C$), note 1		110		
$I_{DD:INIT}$	Operating current during initialization		60	80	110	μA
V_{IH}	Input HIGH-level	Inputs A0, A1, TM and RSTN	$0.7 \times V_{DD}$		$V_{DD} + 0.3$	V
		Inputs SCL and SDA	$0.7 \times V_{DD}$		3.6	V
V_{IL}	Input LOW-level	All digital inputs	$V_{SS} - 0.3V$		$0.3 \times V_{DD}$	V
V_{hys}	Hysteresis of Schmitt trigger inputs	Inputs SCL and SDA	$0.05 \times V_{DD}$			
T_{amb}	Operating temperature range		-40	25	85	$^{\circ}C$
C_{load}	Load capacitance at pin TM				10	pF
R_{RSTN}	Internal pull-up of RSTN			140		k Ω
R_{TM}	Internal pull-up of TM			145		k Ω
$I_{SDA:OL}$	LOW-level sink current of SDA	$V_{OL} = 0.4V$	20			mA
Temperature sensor (Notes 2, 3)						
T_{Error}	Temperature error	$T = 0^{\circ}C$ to $+60^{\circ}C$, $V_{DD} \geq 2.2V$, $T_{RES} = 13$ -bit	-0.5	± 0.3	+0.5	$^{\circ}C$
T_{RES}	Sensor Resolution	11-bit	0.1			$^{\circ}C$
		12-bit	0.05			
		13-bit	0.025			

Notes:

1. Considering one temperature measurement every 60 seconds. Note that the average operating current increases with the measurement time t_M (Table 10: AC characteristics), which depends on the temperature.
2. Assuming a normal distribution, the maximum values correspond to $\pm 3\sigma$ (99.7%) of the circuits.
3. T_{Error} is dependent on V_{DD} and temperature. See section 10.2.1

10.2.1 Temperature Measurement Error

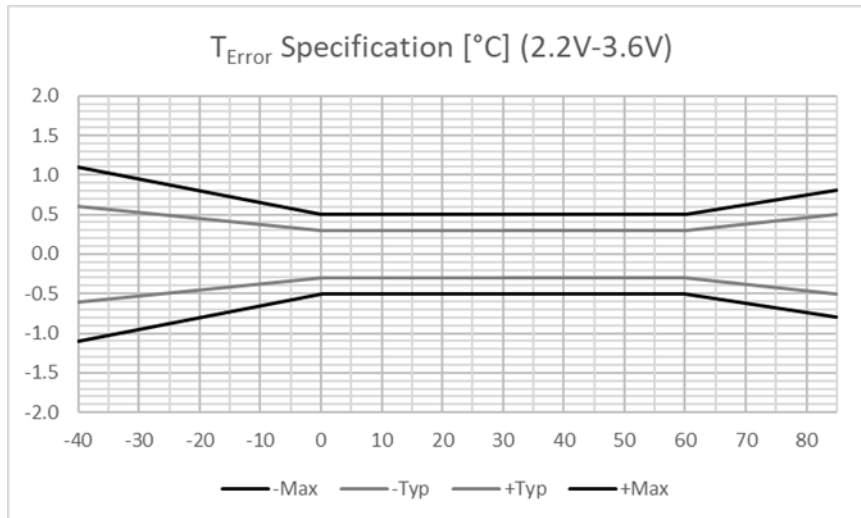


Figure 15: Graphical representation of the specification T_{Error} for $VDD \geq 2.2V$

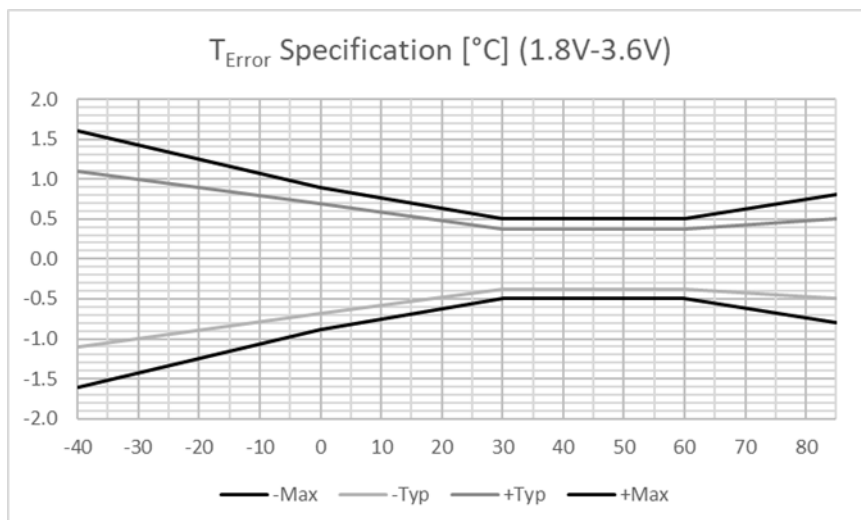


Figure 16: Graphical representation of the specification T_{Error} for $VDD \geq 1.8V$

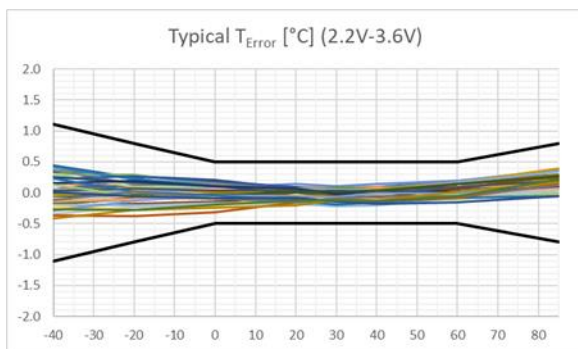


Figure 17: Typical values of T_{Error} for $VDD \geq 2.2V$

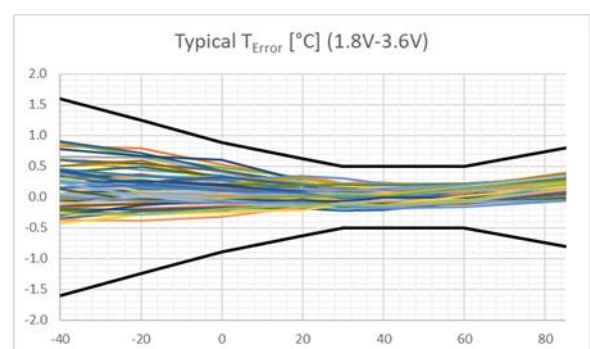


Figure 18: Typical values of T_{Error} for $VDD \geq 1.8V$

10.2.2 Typical DC values

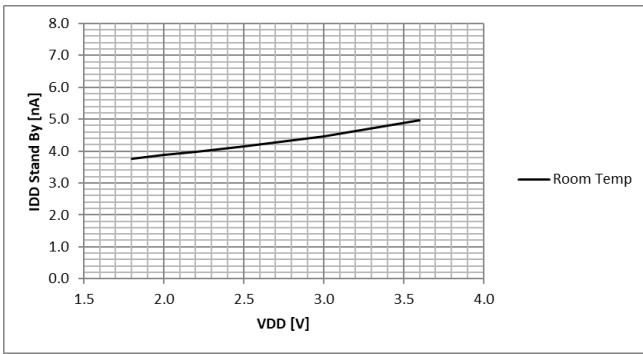


Figure 19: Typical IDD stand-by dependency of VDD

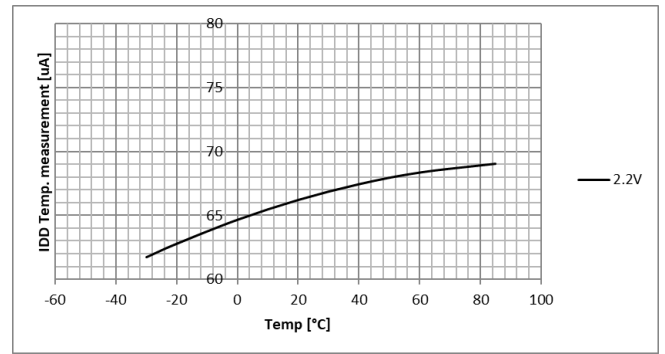


Figure 22: Typical temperature dependency of IDD during temperature measurement

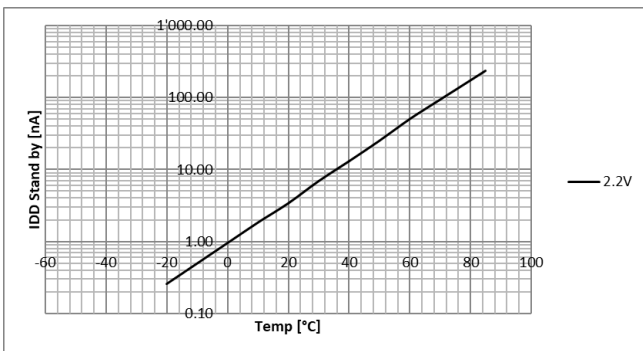


Figure 20: IDD stand-by temperature dependency

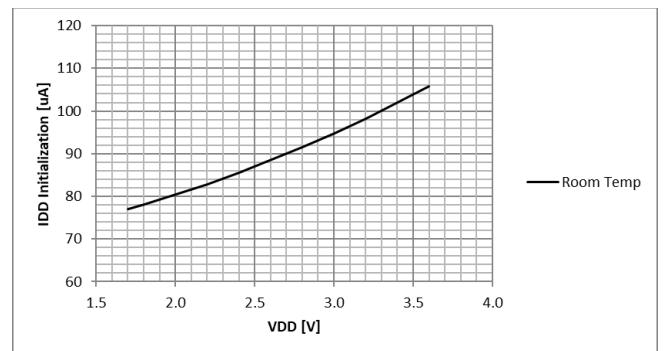


Figure 23: Typical VDD dependency of IDD during initialization (IDD:INIT)

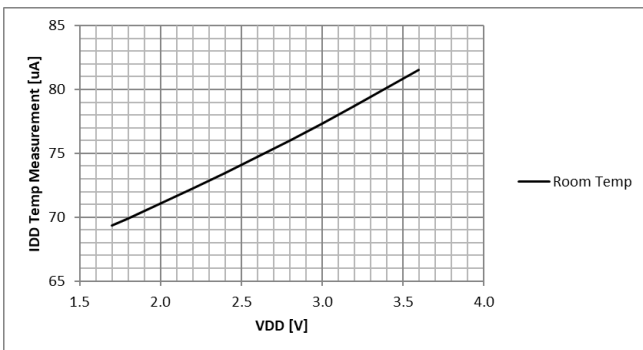


Figure 21: Typical IDD during temperature measurement dependency of VDD

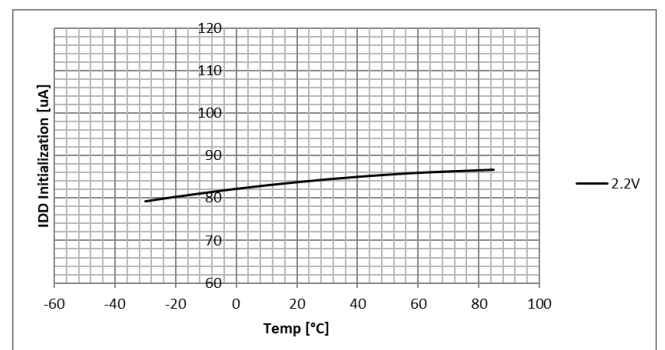


Figure 24: Typical temperature dependency of IDD during initialization (IDD:INIT)

10.3 AC Characteristics

 Table 10: AC characteristics¹
 Conditions: $V_{DD} = 2.2V$, $T = 25^{\circ}C$; unless otherwise specified

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
t_{INIT}	Initialization time after Reset	Figure 4	1.2	1.7	2.1	ms
$t_{TM:START}$	Length of LOW pulse at pin TM	Figure 8	50			ns
t_{RSTN}	Length of Reset pulse	$RSTN=V_{IL}$, $V_{DD} \geq 1.6V$	20			ns
t_M	Temperature measuring time	11-bit	20	24	27	ms
		12-bit	40	47	54	
		13-bit	80	94	107	
I²C Interface (Fast-mode Plus) - Figure 25						
f_{SCL}	I ² C clock frequency		0		1000	kHz
$t_{HD:STA}$	Hold time (repeated) START condition	After this period, the first clock pulse is generated.	0.26			μs
$t_{SU:STA}$	Set-up time (repeated) START condition		0.26			μs
t_{LOW}	LOW period of the SCL clock		0.5			μs
t_{HIGH}	HIGH period of the SCL clock		0.26			μs
$t_{HD:DAT}$	Data hold time			0		μs
$t_{SU:DAT}$	Data set-up time		50			ns
t_r	Rise time of both SDA and SCL signals				120	ns
t_f	Fall time of both SDA and SCL signals		$20 \times (V_{DD} / 5.5V)^2$		120^3	ns
$t_{SU:STO}$	Set-up time for STOP condition		0.26			μs
t_{BUF}	Bus free time between a STOP and START condition		0.5			μs
t_{SP}	Spike suppression ⁴				50	ns

¹ Timings are measured between 30% and 70% of the signal levels.

² Necessary to be backwards compatible to Fast-mode (400kHz)

³ In Fast-mode Plus, fall time is specified the same for both output stage and bus timing. If series resistors are used, designers should allow for this when considering bus timing.

⁴ Spike suppression is implemented on both inputs SDA and SCL.

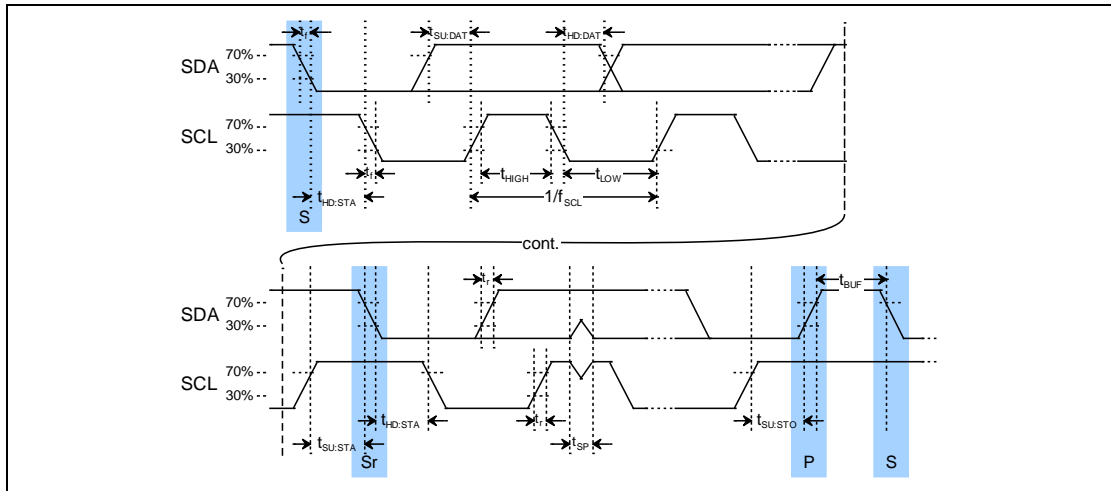


Figure 25: I²C Bus timing

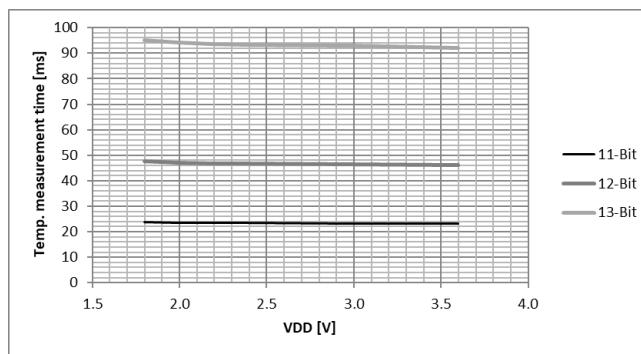


Figure 26: Typical temperature measuring time (t_M) dependency of VDD

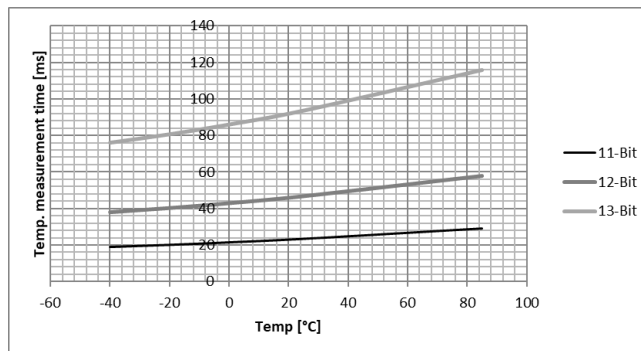
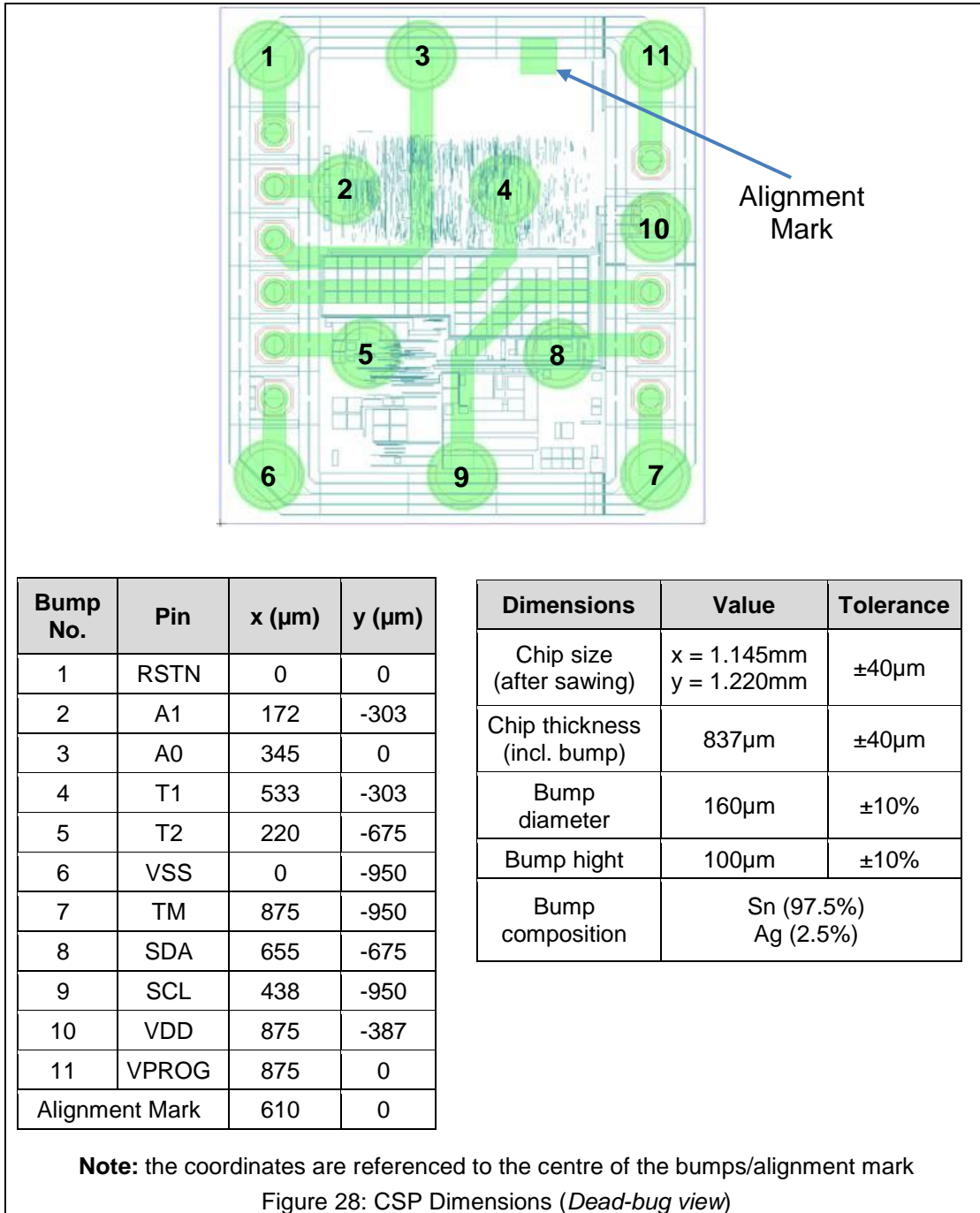


Figure 27: Typical temperature dependency of the temperature measuring time (t_M)

11 CSP Dimensions



12 Legal Disclaimer

This product is not designed for use in life support appliances or systems where malfunction of these parts can reasonably be expected to result in personal injury. A customer using or selling this product for use in such appliances does so at his own risk and agrees to defend, indemnify and hold harmless Microdul AG from all claims, expenses, liabilities, and/or damages resulting from such use of the product.