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 ±0.3°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

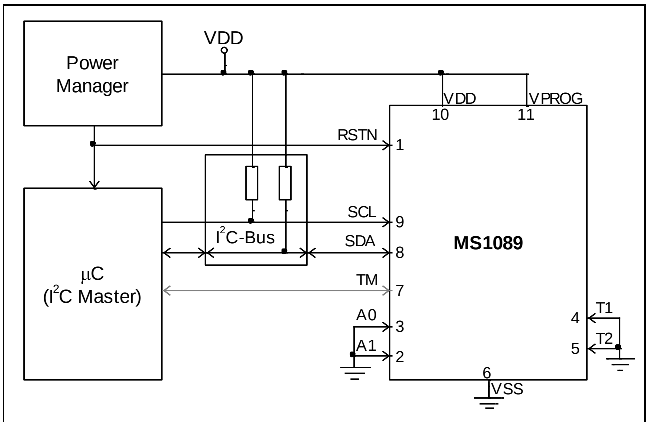

Figure 1: Typical application

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: ±0.3°C from 10°C to +40°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 µA
- Avg. current: 40 nA at 1 measurement per minute
- Supply range: 1.8V to 3.6V
- Available in CSP package

5 Pinout

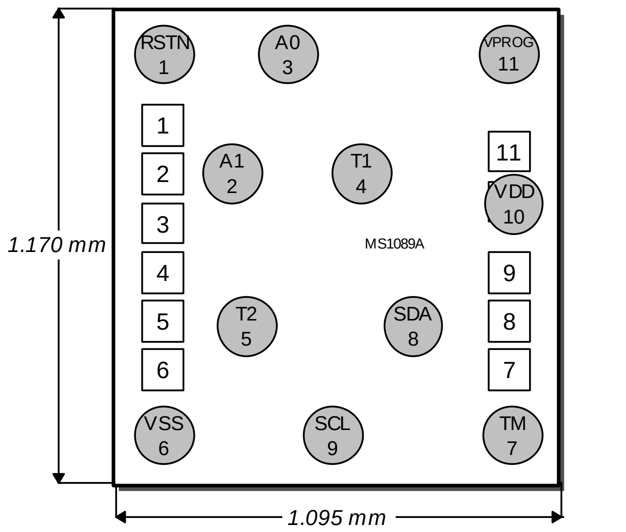

Figure 2: Possible pinout

6 Ordering Information

Table 1: Ordering information

Type	Package	Shipping	Article No.
MS1089	CSP	Tape&Reel	916XXXX

Tel. +41 44 455 35 11, Fax +41 44 455 35 95
http://www.microdul.com/
semiconductors@microdul.com

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^2C sub-address bit 1
3	A0	I	User-defined I^2C 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	Hardware Handshake; open-drain with internal pull-up [3]
8	SDA	I/O	I^2C-bus serial bidirectional data line; open-drain [4]
9	SCL	I	I^2C-bus serial clock input [4]
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, can be left not connected or connected to VDD
3. If pin TM is not used, it must be left not connected
4. SCL and SDA have no internal pull-ups

8 Functional Description

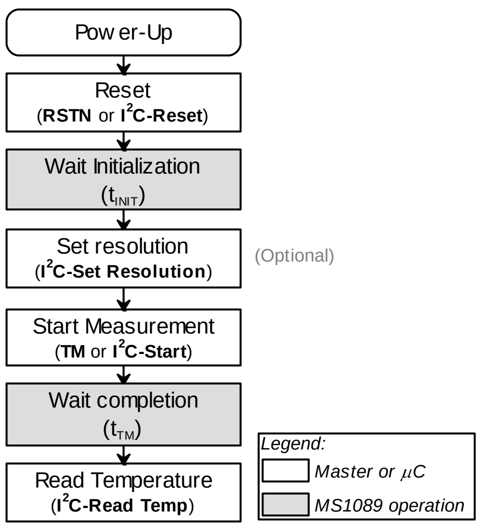

Figure 3: Operation of the MS1089

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 the initialization time t_{INIT} (section 10.3) the power consumption is $I_{DD:INIT}$ (section 10.2).

After reset, the temperature measurement resolution is set to 0.1°C (11 bit).

During initialization the MS1089 will acknowledge I²C commands. It is advisable however not to issue any command other than “set measurement resolution” (I3) until initialization is complete. After initialization the MS1089 is on an ultra-low power state (only leakage current flows).

8.3 Reset and initialization with Input RSTN

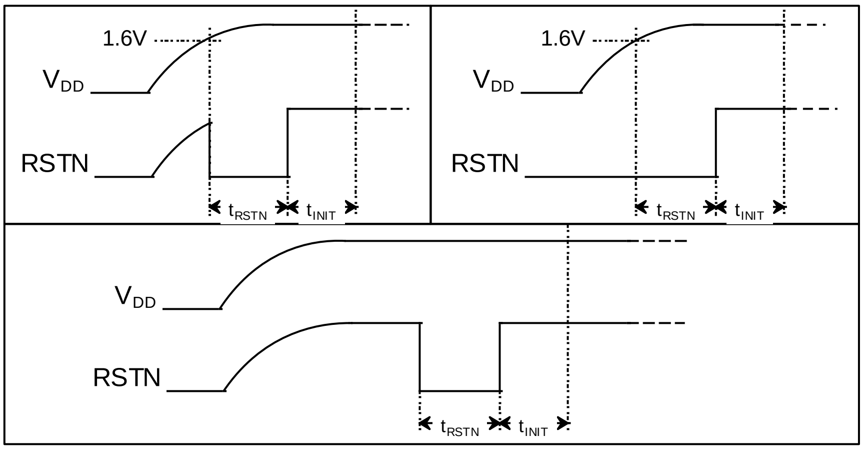

Figure 4: Valid reset strategies at power-up with input RSTN

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.
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 by any reason the pin RSTN cannot be used to initialize the MS1089 after power-up, the I²C command I4 (see Table 7: I²C command table) shall be used for that purpose. In this case it is possible that the state of the I²C circuitry is not well defined, therefore it is advisable to do one of the next two equivalent operations when using the I²C command I4:

1. Clock SCL for 20 to 30 times while SDA remains HIGH before sending the command I4 (Figure 5).
2. Send a *General Call* I²C command (I²C-address 00h) before sending the command I4 (Figure 6). The MS1089 never acknowledges the general call command, therefore the 2nd byte can be any value.

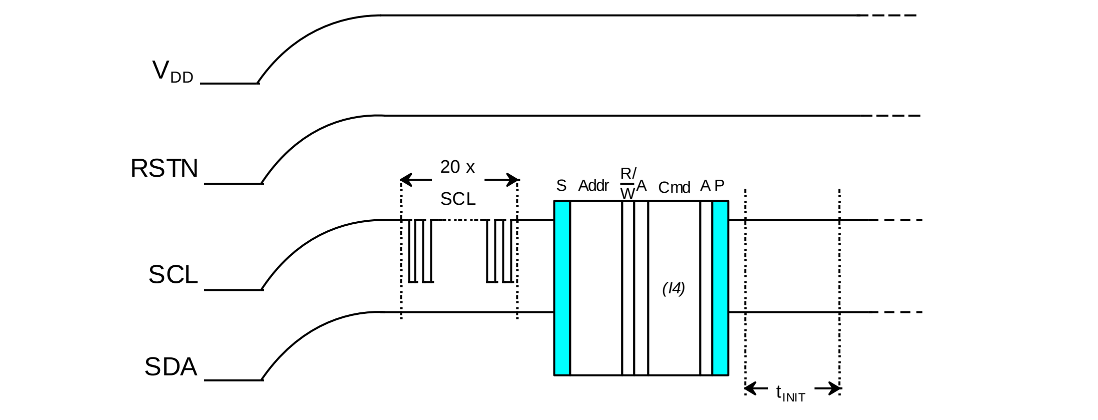

Figure 5: Reset with SCL and I²C-command I4 (option 1)

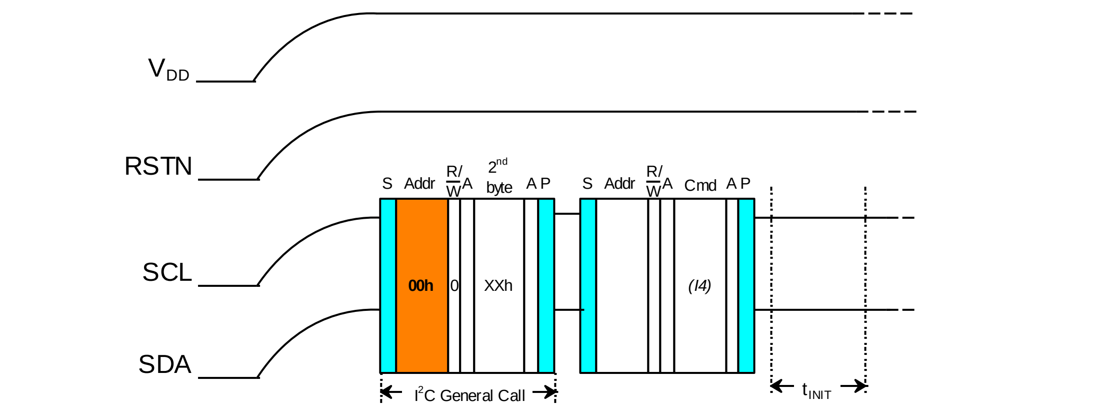

Figure 6: Reset with I²C-commands *General Call* and I4 (option 2)

After sending the I4 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 I3 write command to the MS1089 (Figure 3 and section 9.3).

Notes:

1. The resolution of the thermometer can be only set while the thermometer is idle. While a temperature measurement is ongoing, any request for setting the resolution is ignored

Tel. +41 44 455 35 11, Fax +41 44 455 35 95
http://www.microdul.com/
semiconductors@microdul.com

2. The format of the I²C-Read temperature data TD is always the same, independently of the selected resolution (section 8.6)
3. The time required for the measurement is dependent on the selected resolution (section 10.3). Therefore it also has an impact on the average current consumption $I_{DD:AV}$ (section 10.2)

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

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 command I2 (section 9.3). After completion of the measurement TM is pulled LOW and the MS1089 returns to the ultra-low power mode. The digital value of the temperature is available on the internal register TD and can be read with the I²C command I1.

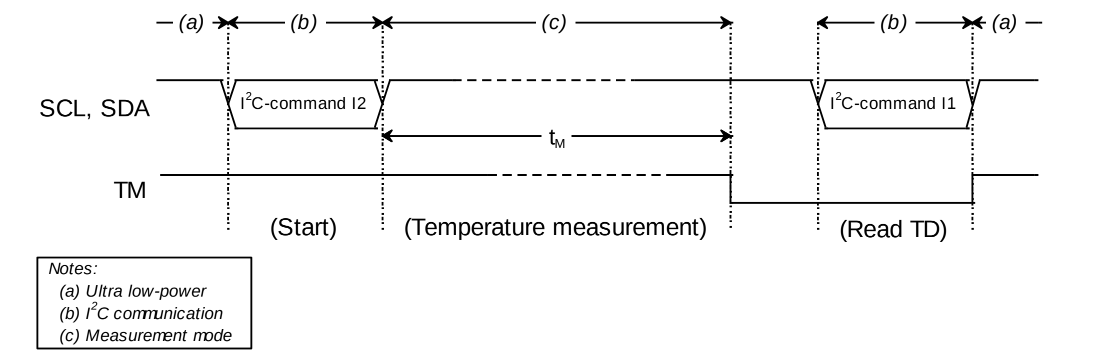

Figure 7: Temperature measurement with I²C

Notes:

1. If a new I²C start measurement command (I2) is sent while a temperature measurement is on-going, the MS1089 generates no acknowledges and the command is ignored
2. If an I²C read temperature command (I1) is sent while a temperature measurement is on-going, the value TD=0 (-80.000°C) is returned
3. When the measurement is complete, the MS1089 pulls down pin TM until TD is read by the command I1

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.

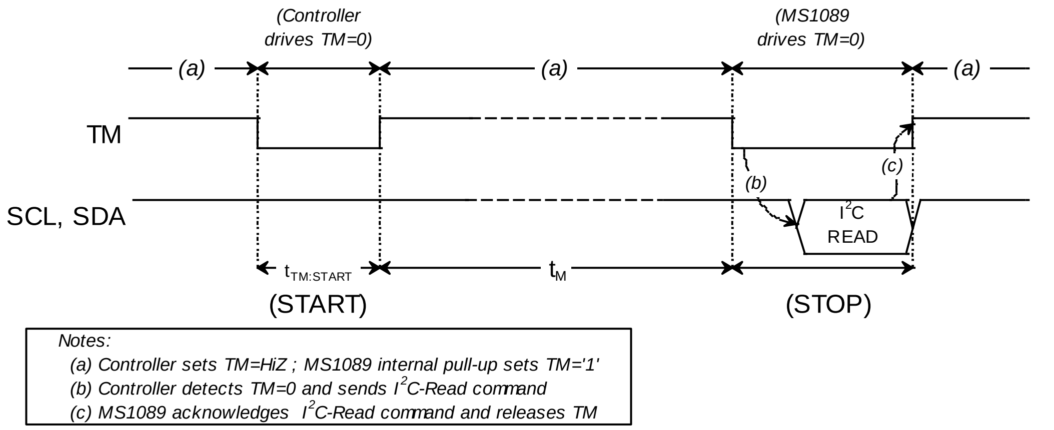

Figure 8: Temperature measurement with the handshake protocol

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 therefore I_{DD} is not affected.
2. If the controller generates a new LOW pulse on TM before the temperature measurement is complete and TD has been read, that pulse is ignored.
3. If two or more MS1089 are used in the application (for example when measuring the temperature in more than one place - see Figure 9), the controller can start all MS1089 simultaneously by pulling down all TM inputs at the same time. In contrast, starting with I²C requires sending sequentially I2 commands (Start Temperature Measurement, see sec. 9.3) to each MS1089.

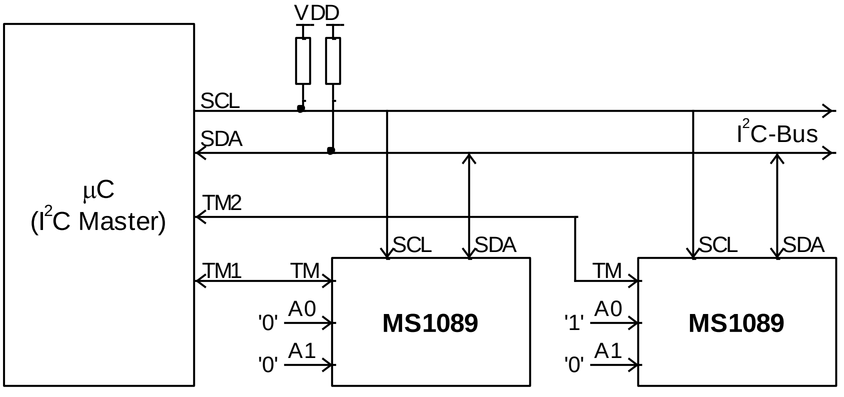

Figure 9: Application using two MS1089

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:

$$\mathrm{T}\ (°\mathrm{C}) = \frac{\mathrm{TD}}{40} - 80$$

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

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	**000**1 0000	0000 0011	4099	22.475
12-bit	**000**1 0000	0000 001**0**	4098	22.45
11-bit	**000**1 0000	0000 00**00**	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. They can therefore be driven to a voltage that is 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 higher voltage like 3.6V, provided the limiting values are not exceeded (section 10.1).

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	1	0	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

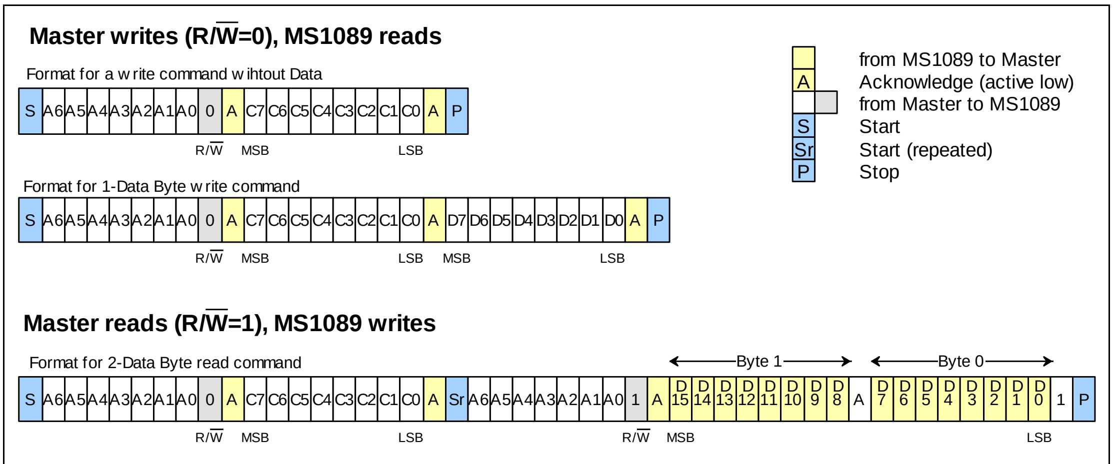

Figure 10: I²C protocol

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 a 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
I4	1	1	0	0-Byte	-	Chip reset

Note:

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.

9.4 I²C communication examples

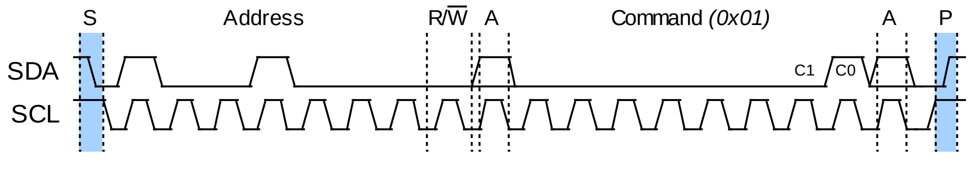

Figure 11: I²C example “Start a temperature measurement”

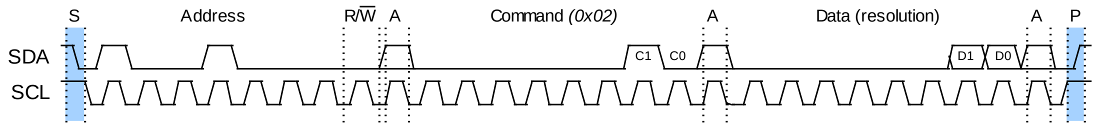

Figure 12: I²C example “Set measurement resolution”

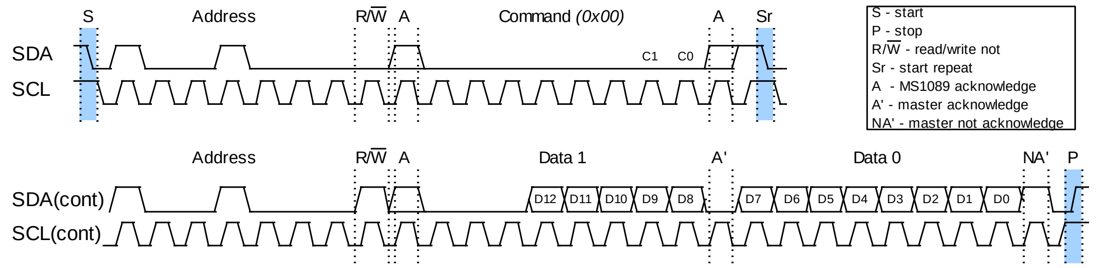

Figure 13: I²C example “Read temperature value TD”

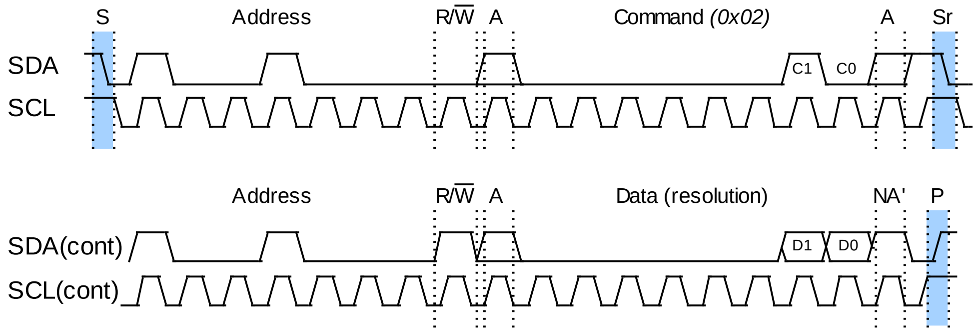

Figure 14: I²C example “Read measurement resolution”

10 Characteristics

10.1 Limiting values and ESD protection

Table 8: Limiting values[1] and ESD Protection[2]

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+0.5	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°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 (Figure 16)		33		nA
		Temperature measurement		70		µA
$I_{DD:AV}$	Average operating current	11 bit (0.1 °C), note 1		68		nA
		12 bit (0.05 °C), note 1		102		
		13 bit (0.025 °C), note 1		172		
$I_{DD:INIT}$	Operating current during initialization			65		µA
V_{IH}	Input HIGH-level	Inputs A0, A1, TM and RSTN	0.7 x V_{DD}		V_{DD} + 0.5	V
		Inputs SCL and SDA	0.7 x V_{DD}		3.6	V
V_{IL}	Input LOW-level	All digital inputs	V_{SS} – 0.3V		0.3 x V_{DD}	V
$V_{SDA:OL}$	Open-drain LOW-level output voltage (output SDA)	3mA sink current VDD > 2.0V	0		0.4	V
		3mA sink current VDD ≤ 2.0V	0		0.2 x V_{DD}	V
V_{hys}	Hysteresis of Schmitt trigger inputs	Inputs SCL and SDA	0.05 x V_{DD}			
T_{amb}	Operating temperature range		-40	25	85	°C
C_{load}	Load capacitance at pin TM				10	pF
R_{PU}	Internal pull-up on pins TM and RSTN			124		kΩ
$I_{SDA:OL}$	LOW-level sink current of SDA	V_{OL} = 0.4V (Note 3)	18.5			mA
Temperature sensor						
T_{Error}	Temperature error (Figure 19)	T = 10°C to +40°C (Notes 2 and 4)		±0.3	±0.5	°C
T_{RES}	Sensor Resolution	11-bit		0.1		°C
		12-bit		0.05		
		13-bit		0.025		
T_{PSVD}	Power supply voltage dependency	Note 4		±0.1		°C/V

Notes:

1. Considering one temperature measurement every 60 seconds. Note that the average operating current increases with the measurement time t_M (section 10.3), which depends on the temperature (Figure 15).
2. Typical values correspond to 97% of the circuits, Maximum values correspond to 99.7% of the circuits.
3. The I²C standard for Fast-mode Plus specifies 20mA worst case.
4. The thermometer of the MS1089 is calibrated at the supply voltage of 2.2V. On Table 9 the temperature error T_{Error} is specified for this supply voltage. When operated at a different supply voltage, T_{Error} must be calculated using the power supply voltage dependency (T_{PSVD}) with the formula:

$$T_{Error}(V_{DD}) = T_{Error}(2.2V) + T_{PSVD} \times |V_{DD} - 2.2|$$

Tel. +41 44 455 35 11, Fax +41 44 455 35 95
http://www.microdul.com/
semiconductors@microdul.com

Example: at V_{DD}=1.8V the typical value of T_{Error} is ±0.34°C (or $\pm(0.3 + 0.1 \times |1.8 - 2.2|)$), the maximum value is ±0.54°C.

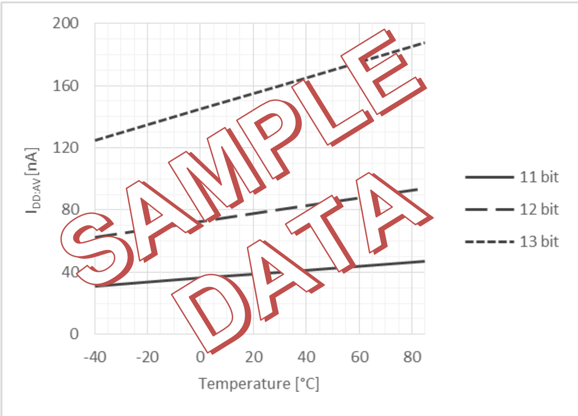

Figure 15: Average supply current (1 measurement/min)

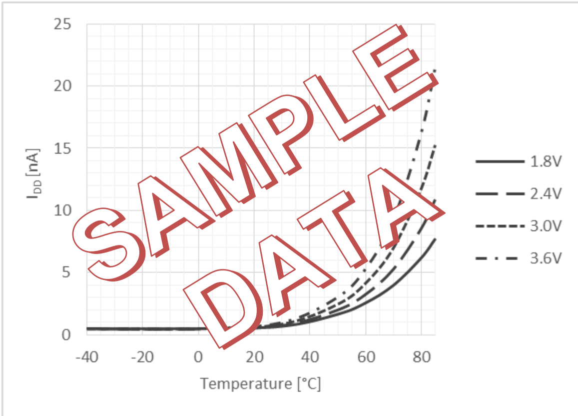

Figure 16: Stand-by current

$I_{DD:INIT}$- TBD

Figure 17: Supply current during initialization

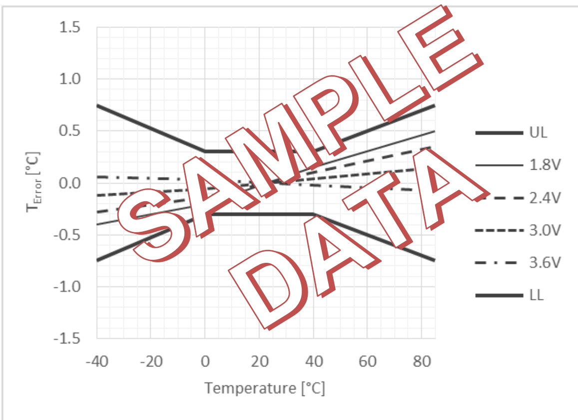

Figure 18: Temperature measurement error

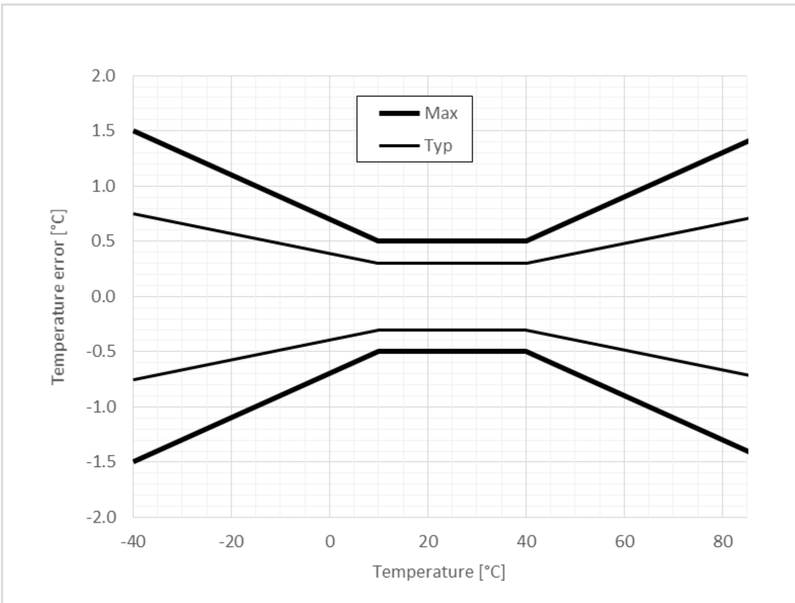

Figure 19: Temperature accuracy at 2.2V

10.3 AC Characteristics

Table 10: AC characteristics[1]
Conditions: V_{DD} = 2.2V, T = 25°C; unless otherwise specified

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
t_{INIT}	Initialization time after Reset	Sections 8.3 and 0		2		ms
$t_{TM:START}$	Length of start LOW pulse at pin TM	Figure 8	50			ns
t_{RSTN}	Length of Reset pulse	RSTN=V_{IL}, V_{DD} ≥ 1.6V	20			ns
t_M	Temperature measuring time (Figure 20)	11 bit		30		ms
		12-bit		60		
		13-bit		120		
I²C Interface (Fast-mode Plus) - Figure 21: I2C Bus timing						
f_{SCL}	I²C 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 x (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.

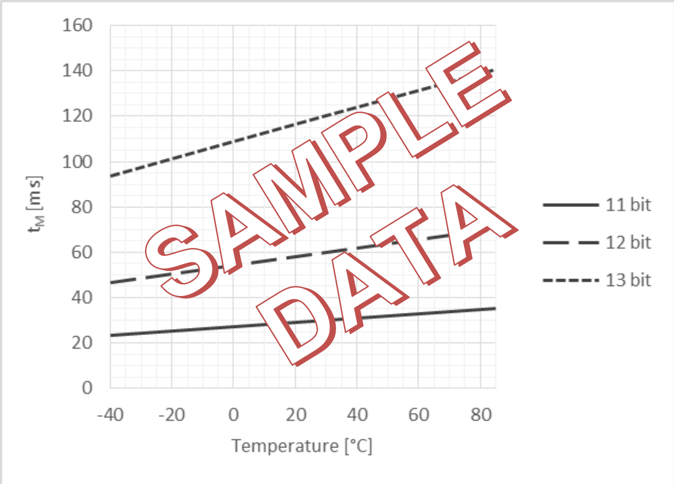

Figure 20: Temperature measurement time

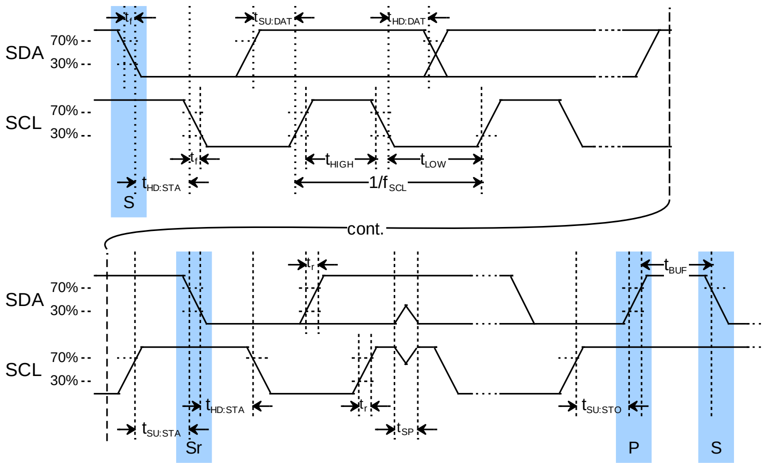

Figure 21: I²C Bus timing

11 CSP Dimensions

Figure 22: 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.

Tel. +41 44 455 35 11, Fax +41 44 455 35 95
http://www.microdul.com/
semiconductors@microdul.com