High Precision Digital Thermometer

T1601 T1601B

Datasheet

Table of contents

1. Overview

The T1601X series is a digital-analog mixed-signal temperature sensor with a maximum measurement accuracy of ±0.1°C, eliminating the need for user calibration. The temperature sensing principle is based on the characteristic relationship between the temperature of a CMOS semiconductor PN-junction voltage. After undergoing small-signal amplification, analog-to-digital conversion, and digital calibration compensation, the output is delivered via a digital bus. This sensor offers advantages including high precision, excellent consistency, fast temperature measurement, low power consumption, flexible programmable configuration, and extended service life.

The sensor incorporates a 16-bit ADC with a resolution of 0.004°C and an ultra-wide operating range from -103°C to +153°C. Each sensor undergoes 100% factory testing and calibration, with compensation coefficients fitted based on temperature error characteristics. Internal compensation calculations are performed automatically. To simplify system implementation, the sensor's ID search, temperature data memory access, and function configuration are all based on One-Wire (OW) protocol commands. The host microprocessor requires only a single GPIO port for read/write access. The One-Wire communication interface provides a low-cost solution for multi-node sensing, data acquisition, and networking by sharing a single data bus. It supports long transmission distances and a large number of nodes, facilitating spatially distributed sensor networking. It supports cascading networks of up to 100 nodes spanning 100 to 500 meters for temperature measurement.

The sensor incorporates a non-volatile E2PROM memory unit for storing the sensor ID number, high/low temperature alarm thresholds, temperature calibration correction values, and user-defined information such as sensor node identification and location data.
High-precision temperature measurement region can be customized upon requirement. For example, for wearable thermometer and cold chain logistics application, the in-fab calibration procedure is different. Therefore the product series is divided into classes of 0.1°C/0.5° C for different working conditions and precision requirement at different price, as shown below.

Part Number	High precision temperature range	Typical Accuracy(°C)	Package (mm)
T1601Z	0℃ to +50℃	±0.1℃	SOT23
T1601W	+20℃ to +70℃	±0.1℃	SOT23
T1601P	-25℃ to +25℃	±0.1℃	SOT23
T1601B	0℃ to +60℃	±0.5℃	SOT23

2. Features

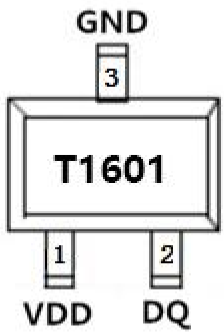
- Temperature measurement range: -103°C to +153°C
- Low power consumption: Typical standby current 0.01μA, average measurement current 2μA (AVG=8, 1 measurement/s)
- Wide operating voltage range: 1.8V to 5.5V
- Customizable measurement accuracy: ±0.1°C / ±0.5°C

- Temperature resolution: 16-bit, 0.004°C
- Configurable temperature conversion time: 15.3ms/8.5ms/5.2ms/2.2ms
- Up to 112-bit additional E2PROM space for user data storage
- Standard one-wire interface
- Heating function for self-diagnostic

3. Applications

- Replacement for PT100/PT1000 solutions
- Replacement for NTC solutions
- Electronic thermometers
- Ultra-low temperature cold chain logistics
- Heat meters, gas meters, water meters
- Board-level temperature monitoring
- Industrial instrumentation
- Power terminal temperature measurement

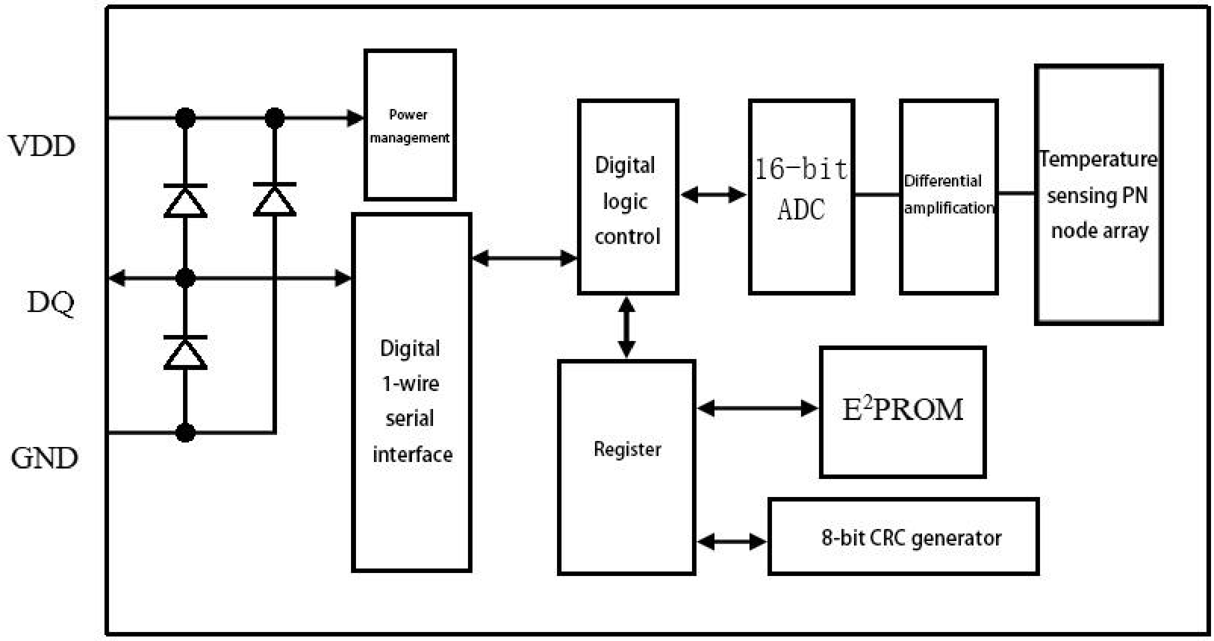
4. Package pin description



Front View

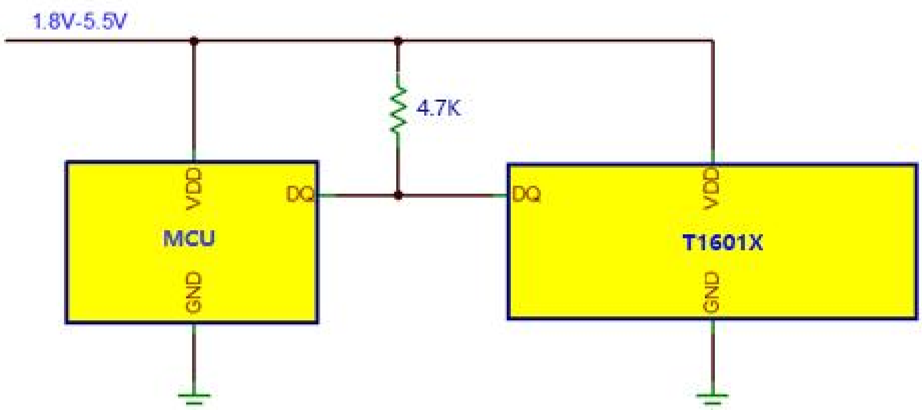
No.	Pin Name	I/O	Description
1	VDD	—	Power
2	DQ	I/O	One-wire data line
3	GND	—	Ground

5. System Diagram



The principle diagram of the temperature sensor is shown above. The register includes two bytes of the temperature register, storing the digital output from the sensor. Additionally, the register and extended register provide alarm trigger threshold registers. The configuration register allows users to set the temperature conversion repeatability and continuous measurement frequency. The status register can query the alarm status. Data can be stored in non-volatile memory, and data will not be lost when the sensor is powered off.

6. Typical Application Circuit



Note 1: For long cables or multi-point slave conditions, ensure the supply voltage remains above 3.3V whenever possible.

Note 2: For long cables or multi-point slave conditions, prioritize a 1K pull-up resistor value.

Note 3: Under 5V voltage and 1K pull-up resistor conditions, a single bus can drive up to 100 T1601X devices with a maximum cable length of 500 meters.

7. Temperature Sensing Performance

Parameter	Symbol	Condition	Min	Typical	Max
Temperature Range	—	—	-103℃	—	+153℃
Temperature error	t_{ERR}	T1601Z	—	—	±0.1℃@0℃ to +50℃ ±0.2℃@-10℃ to +60℃ ±0.5℃@-25℃ to +75℃
		T1601W	—	—	±0.1℃@+20℃ to +70℃ ±0.2℃@0℃ to +75℃ ±0.5℃@-20℃ to +90℃
		T1601P	—	—	±0.1℃@-25℃ to +25℃ ±0.5℃@-55℃ to +55℃
		T1601B	—	—	±0.5℃@0℃ to +60℃
		T1601X	—	±2℃@-103°C to +153°C	—
Repeatability	—	AVG=1	—	0.02℃	(1)
		AVG=8		0.01℃	—
		AVG=16	—	0.008℃	—
		AVG=32	—	0.007℃	—
Resolution	—	—	—	0.004℃	—
Long Term Drift	—	—	—	—	0.03°C/年

Note1: The higher the average number, the longer the conversion time, and the higher the measurement accuracy, see Table 9.3-2.

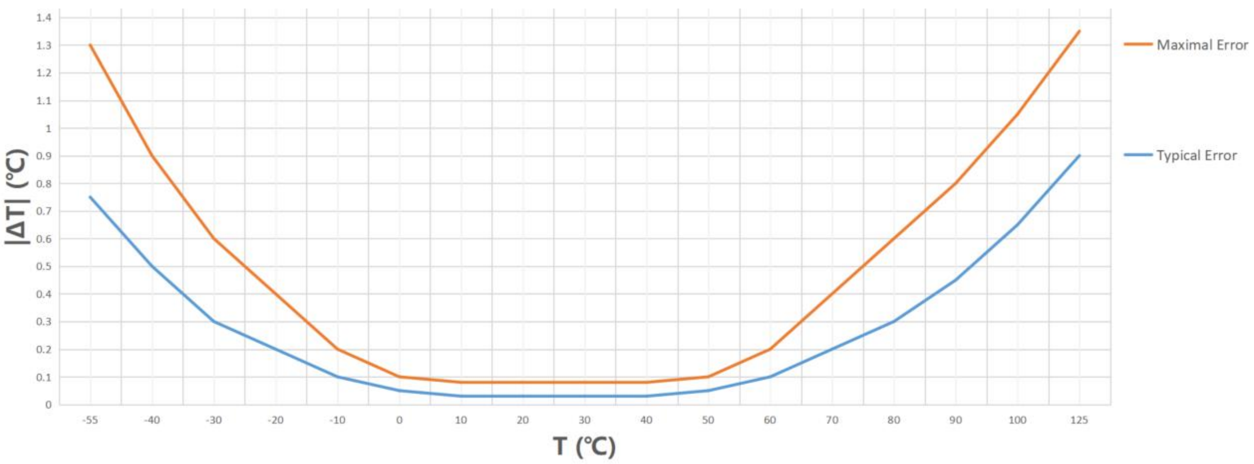


Figure 7-1 T1601Z Accuracy Error Curve

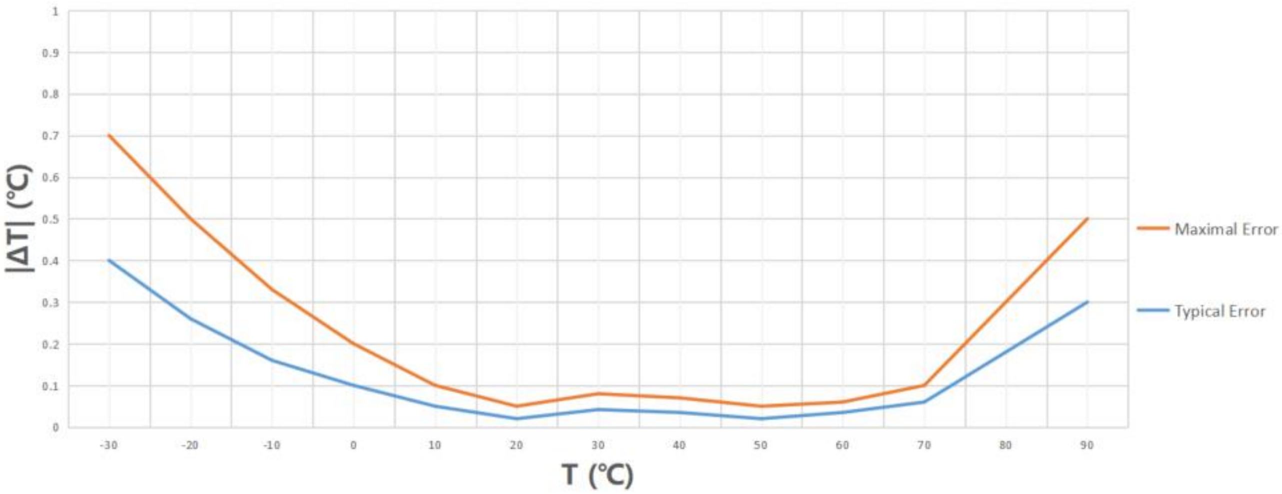


Figure 7-2 T1601W Accuracy Error Curve

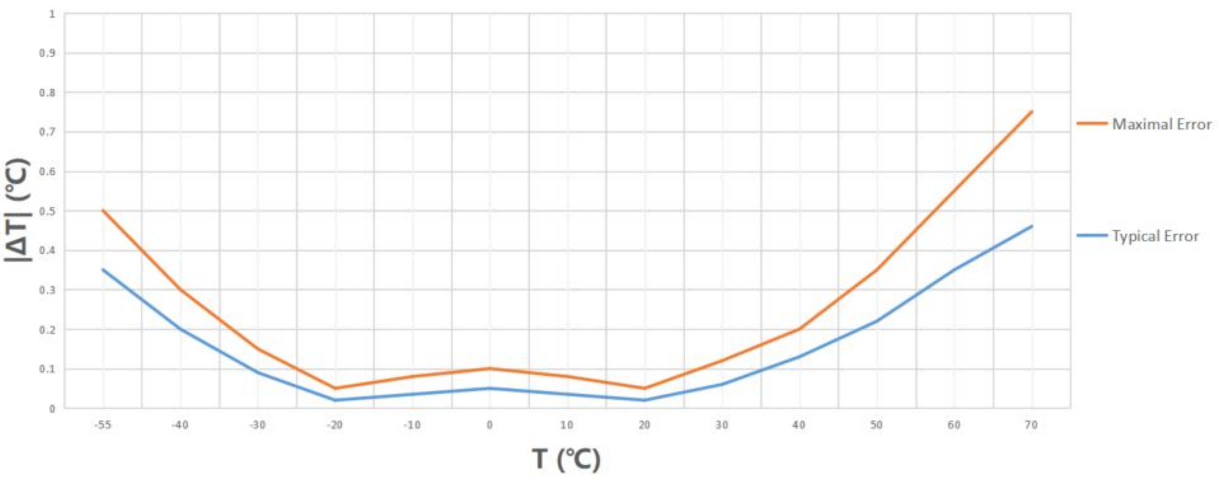


Figure 7-3 T1601P Accuracy Error Curve

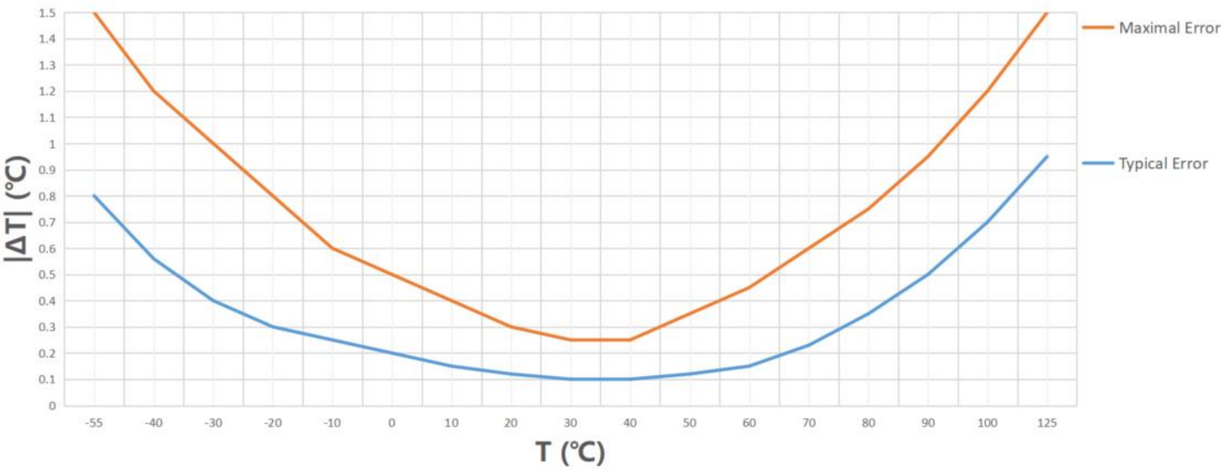


Figure 7-4 T1601B Accuracy Error Curve

8. Electrical Specifications

8.1 Absolute Maximum Ratings

The following are limit parameters. This specification does not apply to the functional operation of the device under these limit conditions or in environments exceeding these limits. Please note that prolonged exposure to these limit conditions may affect the reliability of the device.

Parameter	Rating	Unit
Supply Voltage VDD	-0.3 to 6	V
Pin Voltage	-0.3 to 6	V
Pin Current	±100	mA
Operating junction temperature	-103 to 153	℃
Storage Temperature Range	-103 to 153	℃
Soldering Temperature	per IPC/JEDEC J-STD-020 specification	
ESD HBM (Human-body model)	±8	kV

8.2 Electrical Characteristics

Typical specifications are at T=25℃ and VDD=3.3V。

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNIT	NOTE
Power Supply							
Operating voltage range	VDD	—	1.8	3.3	5.5	V	Supply voltage
Quiescent current	IDD	Idle State (Single Measurement Mode)	—	0.01	—	uA	Idle current in single measurement mode
		Idle State (cycle Measurement Mode)	—	50	—	uA	Standby current in cycle measurement mode
		Active Conversion	—	360	—	uA	Active Conversion
		Average	—	2	—	uA	Single measurement mode, AVG=8, 1 measurement/s
Digital input/output							
Input Logic Low	VIL	SCL, SDA	—	—	0.3*VDD	V	
Input Logic High	VIH	SCL, SDA	0.7*VDD	—	—	V	
output Logic low	VOL	IOL = -3 mA	—	—	0.4	V	
Input leakage current	IIN	—	-0.1	—	0.1	uA	
Pull-up resistor	Rup		1	4.7	10	kΩ	

8.3 AC Electrical Characteristics - Non-Volatile Memory

-55℃~+125℃; V_{DD}=1.8V~5.5V

Parameter	Symbol	Condition	MIN	TYP	MAX	Unit
Write time	t_{WR}	—	—	—	40	ms
E^2PROM Write Cycles	N_{EEWR}	-55°C to+55°C	50000	—	—	cycles
E^2PROM Data Retention	t_{EEDR}	-55°C to +55°C	—	10	—	years

9. Functional Description

Upon powering up the sensor, it enters an idle state awaiting a command from the host to initiate temperature measurement. After the conversion time, the 16-bit temperature data is stored in the temperature register (Temp_lsb/Temp_msb) and is available for reading. The conversion time and average counts setting are related; the more the average counts, the longer the conversion time. For details on average counts and corresponding temperature conversion times, refer to Section 9.3.

9.1 Temperature Output and Conversion Formula

The digital output of the temperature is a 16-bit signed binary code with the LSB resolution of 1/256°C, and S is the sign bit, the data is stored in the Temp_lsb and Temp_msb registers.

Table 9.1 Temperature register（Temp_lsb/Temp_msb）, address 0x00 & 0x01

	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
high byte	2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}	2^{-6}	2^{-7}	2^{-8}
	bit15	**bit14**	**bit13**	**bit12**	**bit11**	**bit10**	**bit9**	**bit8**
Low byte	S	2^6	2^5	2^4	2^3	2^2	2^1	2^0

The conversion relationship between Celsius and Celsius is:

$$T[℃] = \frac{S_T}{256} + 25$$

For example,

25°C corresponds to the register value of 0x00 00
153°C corresponds to the register value of 0x7F FF
-103°C corresponds to the register value of 0x80 00

9.2 Command Registers

The Temp_Cmd register includes the measurement mode and heater configuration bits, detailed as follows:

table 9.2 temperature measurement command register（Temp_Cmd）， address 0x04

Bit	Description	Default Value
7:6	Measurement mode selection (Measurement) 00/10: Continuous measurement mode, readback value 00 01/11: Single measurement mode	
5:4	reserve	‘00’
3:0	Heater function 1010: Heating function on Others: Heating function off, readback value 0000	‘0000’

Upon power-up, the sensor defaults to single measurement mode, awaiting a measurement command from the host. In single measurement mode, only one temperature conversion is performed. After completion, the sensor enters sleep mode unless bit 0 of the temperature configuration register (Temp_Cfg) is set to 0. Continuous measurement mode performs periodic temperature measurements based on bits 7 through 5 (MPS) of the temperature configuration register (Temp_Cfg). The sensor remains active between conversions and does not enter sleep mode, even if bit 0 of the Temp_Cfg register is set to 1. In continuous measurement mode, the sensor exits this mode upon receiving a Break command from the host. The host must send a one-wire temperature measurement command (ConvertT) to trigger the sensor's measurement function.

9.3 Configuration Register

The configuration register (Temp_Cfg) includes configuration bits for cycle measurement frequency, temperature measurement average number of times, low power mode, etc., as described below:

Table 9.3-1 Configuration Register (Temp_Cfg), Address 0x05

Bit	Description	Default Value
7:5	Measurements per second configuration (MPS) 000: 8 per second 001: 4 per second 010: 2 per second 011: 1 per second 100: 1 time in 2 seconds 101: 1 time in 4 seconds 110: 1 time in 8 seconds 111: 1 time in 16 seconds	‘011’
4:3	Temperature measurement average number of configurations (AVG) 00: AVG=1 01: AVG=8 10: AVG=16 11: AVG=32	‘11’

2:1	reserve	'00'
0	Low power mode switch (Sleep_en) 0: do not enter low-power mode after executing the instruction 1: Enter low-power mode after executing instructions	'1'

Table 9.3-2 Correspondence between average frequency and conversion time

AVG[1:0]		Number of data	Conversion time t_{CONV}
0	0	1	2.2ms
0	1	8	5.2ms
1	0	16	8.5ms
1	1	32	15.3ms

9.4 Status Register

The Status register (Status) is in read-only mode and contains information such as temperature transition status, alarm status, E^2PROM status, heating status, etc. It is described as follows:

Table 9.4 Status Register, Address 0x03

Bit	Description			Default Value
7	Temperature high line alarm tracking	0: Temperature alarm not triggered	1: Temperature alarm trigger	'0'
6	Temperature low line alarm tracking	0: Temperature alarm not triggered	1: Temperature alarm trigger	'0'
5	Temperature transition state	0: Temperature conversion complete	1: During temperature conversion	'0'
4	E^2PROM status	0: not in read/write state	1: In read/write state	'0'
3	heating state	0: not in heating state	1: In a heated state	'0'
2	Temperature alarm error indication	0: TH is greater than TL	1: TH is less than or equal to TL	'0'
1:0	reserve			'00'

Bit 5 indicates the status flag signal for temperature measurement. When temperature measurement is in progress, bit 5 in the status register is set to 1; when temperature measurement is complete, bit 5 in the status register is cleared to 0.

9.5 CRC Check Function

The sensor includes a CRC data checksum function to improve communication reliability. the CRC value is stored in a specific address byte, which corresponds to the following register combination:
(1) The CRC checksum value of 2 bytes of data from address bytes 0x00 to 0x01 is made as Crc_temp and stored in address byte 0x02;
(2) The CRC checksum value of 8 bytes of data from address bytes 0x03 to 0x0A, done as Crc_scratch, is stored in address byte 0x0B;
(3) The CRC checksum value of 10 bytes of data from address bytes 0x0C to 0x15, done as

Crc_scratch_ext, is stored in address byte 0x16.
The computational polynomial for the specific CRC is:

$$CRC = X^8 + X^5 + X^4 + 1$$

This algorithm circuit consists of shift register and iso gate circuit with initial value 0x00 and has the following structure:

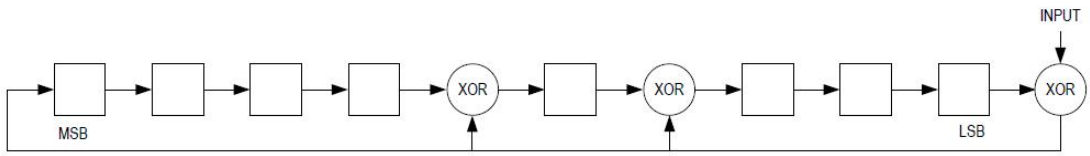


Figure 9.5 CRC generator

When using the Match ROM command in 1-wire bus mode, the three CRC checksum bytes need to be calculated together by adding the first 7 bytes of the ROM code before the value of registers, corresponding to the following register combination:
(1) The CRC checksum value for the9 bytes of data from address bytes 0x18 to 0x1E, 0x00 to 0x01, as Crc_match_temp, is stored in address byte 0x02;
(2) The CRC checksum value for the 15 bytes of data from address bytes 0x18 to 0x1E, 0x03 to 0x0A, as Crc_match_scratch, is stored in the address byte 0x0B;
(3) The CRC checksum value for the 17 bytes of data from address bytes 0x18 to 0x1E, 0x0C to 0x15, as Crc_match_scratch_ext, is stored in the address byte 0x16.

9.6 Alarm function

Alert mode is used to monitor ambient temperature, achieved by configuring the Alert_Mode register and the high/low threshold registers (Th/Tl). Additionally, dedicated bits within the Status register indicate alert status, as detailed in Section 9.4.
The Alert_Mode register includes configuration bits for alert enable, mode selection, and other settings. The specific configuration of this register is described as follows:

Table 9.6 Alert Mode Register (Alert_Mode), Address 0x06

Bit	Description	Default Value
7	Alarm function switch (Alert_en) 0: Closed 1: Open	‘0’
6	Alarm mode (IM) selection 0: Above TH alarm and below TL release alarm 1: Above TH alarm and below TL alarm	‘0’
5:0	reserve	‘0000’

The alarm threshold registers include the high threshold register (Th) and the low threshold register (Tl), both of which correspond to the resolution of the temperature registers (Temp_lsb/Temp_msb), as described in Section 9.1. The 16-bit signed number of the alarm threshold will be compared with the 16-bit standard output temperature value to determine whether the alarm condition has been met, so the resolution of the temperature alarm threshold is the same as temperature sensing resolution $\Delta T \approx 0.004°C$.

When the alarm function is enabled, the alarm mode activates whenever the sensor performs a measurement operation. To disable the alarm function, the host can set bit 7 of the alarm configuration register (Alert_Mode) to 1. Alternatively, the alarm function can be disabled by setting the alarm lower threshold value to be greater than or equal to the alarm upper threshold value (Tl≥Th). By modifying the alarm mode bit (IM) in the alarm mode register, the following alarm modes can be implemented:

(1) Higher than the high limit alarm, lower than the low limit release alarm mode.

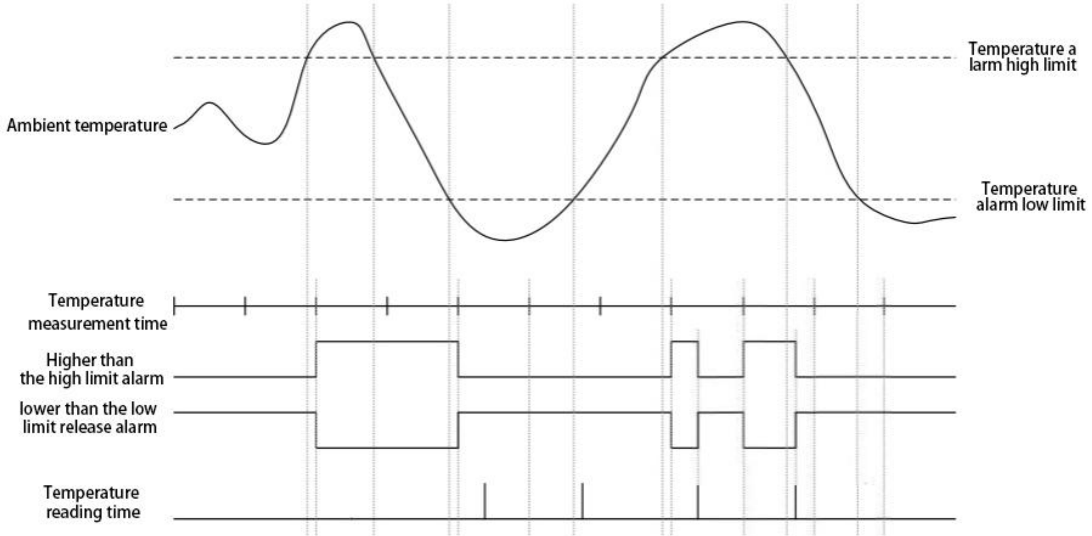


Figure 9 .6-1 Timing diagram for alarm above high limit and de-alarm mode below low limit

This mode corresponds to IM=0, bit7 in the status register (Status) is the same as the flag bit of the above figure for exceeding the high limit alarm, and bit6 is 0.

(2) Above high limit alarm, below low limit alarm mode .

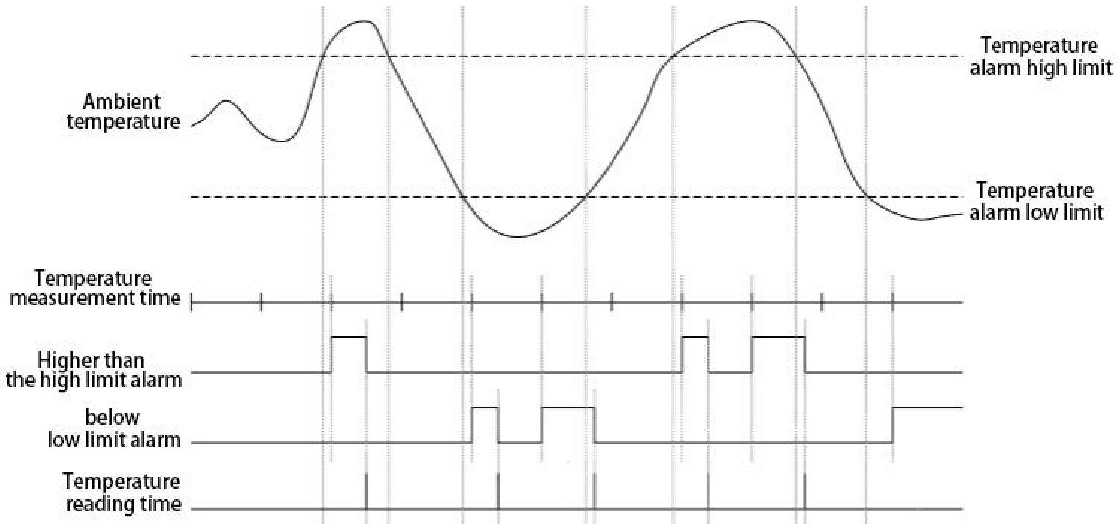


Figure 9 .6-2 Timing Diagram for Alarm Above High Limit, Alarm Below Low Limit Modes

This mode corresponds to IM=1, bit7 in the status register (Status) is the same as the flag bit for exceeding the high limit alarm as shown above, and bit6 is the same as the flag bit for falling below the low limit alarm as shown above.

9.7 Heating as a Self-diagnosis Function

The sensor is equipped with an internal heating resistor for heating the sensor, and the host can read the temperature value before and after heating to determine whether the sensor temperature measurement function is normal. The heating power is 7.8mW, and the temperature increase is above

0.1 ° C. The temperature measurement function is performed by the temperature measurement command register (Temp_cmd). The function is activated and deactivated by bit3~bit0 in the Temperature Command Register (Temp_cmd), and the configuration details are shown in section 9.2.

9.8 Soft Reset

The host can realize the soft reset function of the sensor by writing 0x6A to the E^2PROM command register (E^2PROM_Cmd). During soft reset, the register values that have correspondence with E^2PROM will be reloaded, and other register values that do not have correspondence with E^2PROM will be reset to the power-on default values. For the correspondence of specific registers with E^2PROM, please refer to Section 10.

9.9 Parasitic-power Power Mode

T1601X can be powered by an external power supply connected to the VDD pin or operate in parasitic-power-power mode, enabling operation without an external power source. The circuit diagram below shows the sensor in parasitic-power mode. The MCU's VDD supply range is 2.5V to 5.5V. When DQ is high, power is "snatched" through the DQ pin. When DQ is high, a portion of the charge is stored in the energy storage capacitor (C) to power the sensor when the bus is low. In parasitic-power mode, the energy storage capacitor can provide sufficient current to the sensor as long as the specified capacitance and voltage requirements are met (see DC characteristics and AC characteristics). The recommended pull-up resistor R value is 4.7kΩ to 10kΩ, adjustable based on specific application conditions. The energy storage capacitor C should not be less than 100nF. Provided that the sensor's VDD port has a 100nF capacitor, the parasitic-power mode can be implemented in the following two ways:

(1) External Schottky diode, energy storage capacitor

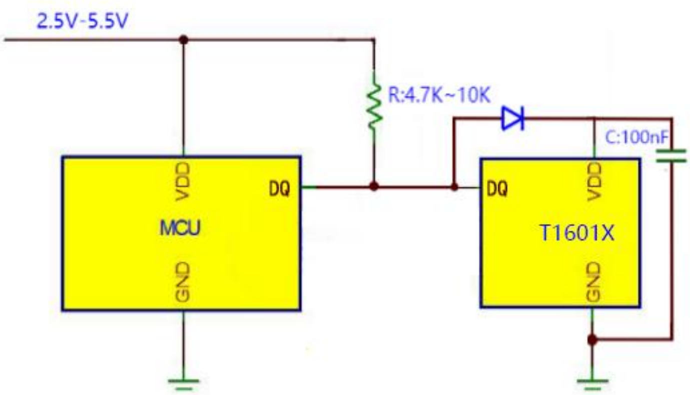


Figure 9.9-1 Parasitic-Power Mode Typical Circuit Diagram (External Diode Configuration)

T1601X can be used directly in parasitic-power mode after connecting the hardware according to the circuit diagram.

Note: The forward voltage drop of the Schottky diode shown in the diagram should not exceed 0.4V. Its functions are:

① Preventing an increase in the sensor's static operating current;

② Preventing stored charge on capacitor C from flowing back to DQ when DQ transitions from high to low.

(2) External energy storage capacitor, modify internal register parameters

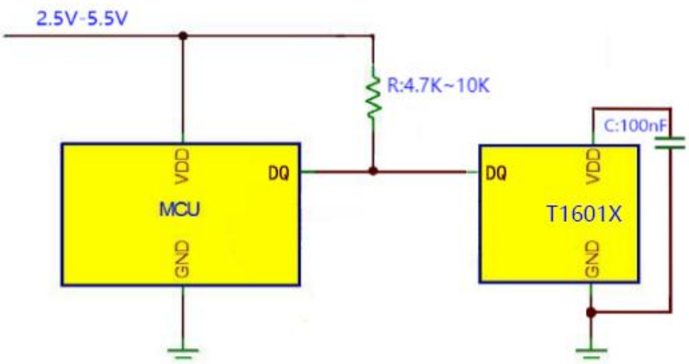


Figure 9.9-2 Typical Circuit Diagram for Parasitic-Power Mode (Register Modification Method)

When using this method, the steps to enable parasitic-power mode are as follows:

1、With the T1601X sensor powered by an external VDD supply, modify bits 3 to 0 of the Misc_Cfg register to b'1010 to switch to parasitic-power mode. Refer to Table 9.6-1 for register specifications.

2、Maintain DQ at a high level. Disconnect the sensor's VDD port from the external power supply. Using one-wire parasitic-power mode, issue the Copy command to store the modified configuration into the E2PROM. This ensures the sensor directly enters parasitic-power mode upon subsequent power-up.

Notes:

(1) In parasitic-power mode, apply a strong pull-up to the DQ bus during temperature conversion and Copy command execution to maintain a stable high level and ensure command success.

(2) Contact the manufacturer to obtain the modification command and Copy command for one-wire parasitic-power mode.

9.10 Sensor ID

The sensor ID is 64 bits and is stored in the sensor ID register (Romcode) in the format:

Table 9.10 Sensor ID Registers (Romcode), Addresses 0x18 ~ 0x1F

Bit	Register Name	Register address	Power on reset default value
7:0	Romcode1	0x18	0x01
15:8	Romcode2	0x19	0x16
16:23	Romcode3	0x1A	Factory value
24:31	Romcode4	0x1B	Factory value
32:39	Romcode5	0x1C	Factory value
40:47	Romcode6	0x1D	Factory value
48:55	Romcode7	0x1E	Factory value
56:63	crc_romcode	0x1F	Factory value

10. Storage System

10.1 Register Table

The sensor's register and memory are organized as shown in Table 10.1. The memory contains an SRAM register as well as expanded storage non-volatile storage E^2PROM for storing the high and low temperature alarm trigger lines (Th and Tl), the temperature configuration register (Temp_Cfg), the alarm mode register (Alert_Mode), and the 10-byte user programmable region (User_define). Note that the Alarm High (Th) and Alarm Low (Tl) registers can be used as general-purpose memory areas if the sensor's alarm function is not being used. All memory function definitions are described in detail in Section 9.

Table 10.1 Register table and E^2PROM Mapping

Register Name	Bit width	Register address	1-wire bus read	1-wire bus write	E^2PROM address	1-wire bus read	1-wire bus mount E^2PROM	Power on reset default value
Temp_lsb	8	00h	Read temperature (0xBC)	NA	NA	NA	NA	00h
Temp_msb	8	01h		NA	NA	NA	NA	00h
Crc_temp	8	02h		NA	NA	NA	NA	NA
Status	8	03h	Read scratchpad (0xBE)	NA	NA	NA	NA	00h
Temp_Cmd	8	04h		Write config (0x4E)	NA	NA	NA	40h
Temp_Cfg	8	05h			00h	Copy page (0x48)	Recall EE (0xB8) / Recall page (0xB6)	79h
Alert_Mode	8	06h			01h			00h
Th_lsb	8	07h			02h			FFh
Th_msb	8	08h			03h			7Fh
Tl_lsb	8	09h			04h			00h
Tl_msb	8	0Ah			05h			80h
Crc_scratch	8	0Bh		NA	NA			NA
User_define_0	8	0Ch	Read scratchpad extension (0xDD)	Write scratchpad extension (0x77)	06h			00h
User_define_1	8	0Dh			07h			00h
User_define_2	8	0Eh			08h			00h
User_define_3	8	0Fh			09h			00h
User_define_4	8	10h			0Ah			00h
User_define_5	8	11h			0Bh			00h
User_define_6	8	12h			0Ch			00h
User_define_7	8	13h			0Dh			00h
User_define_8	8	14h			0Eh			00h
User_define_9	8	15h			0Fh			00h
Crc_scratch_ext	8	16h		NA	NA	NA	NA	NA
E^2PROM_Cmd	8	17h	NA	NA	NA	NA	NA	00h
Romcode1	8	18h	Read	NA	NA	NA	NA	01h

Romcode2	8	19h	romcode (0x33)	NA	NA	NA	NA	16h
Romcode3	8	1Ah		NA	10h	NA	Recall EE (0xB8)	(1)
Romcode4	8	1Bh			11h			(1)
Romcode5	8	1Ch			12h			(1)
Romcode6	8	1Dh			13h			(1)
Romcode7	8	1Eh			14h			(1)
crc_romcode	8	1Fh		NA	NA			NA
Misc_Cfg	8	63h	(2)	(2)	(2)	(2)	(2)	00h
Mode_Cfg	8	68h	(2)	(2)	(2)	(2)	(2)	00h

Note:

(1) This byte is the factory value.

(2) Modifications to this byte are associated with other bytes used for internal testing. Modification instructions can be obtained by contacting the manufacturer.

10.2 E2PROM

The host must send specific E2PROM function commands to trigger corresponding E2PROM operations. To permanently write data from registers to E2PROM, the host must issue a Copy command. Data stored in E2PROM registers persists during power loss and automatically loads into corresponding register locations upon power-up. Data can also be reloaded by the host issuing a Recall command. Note that writing to the E2PROM is performed in 16-byte blocks. Ensure all 16 registers contain correct data before executing a unified copy operation.

The operating status of the E^2PROM is reflected in bit4 of the status register (Status): when the E^2PROM read/write is in progress, bit4 of the status register = 1; when the E^2PROM read/write is finished, bit4 of the status register = 0.

10.3 1-Wire Instructions

The T1601X employs a 1-wire bus communication method. Table 10-3 provides the operating procedures for different functions on the 1-wire bus.

Table 10.3 List of 1-wire bus Functions

Name	Function	1-wire bus command
search rom	Search for romcode	0xF0
read rom	Read romcode	0x33
match rom	Match rmcode	0x55
skip rom	Ignore romcode	0xCC
alarm search	Search for Alarm Sensors	0xEC
convert temperature	measured temperature	0x44
read temperature	Read two bytes of the temperature value	0xBC
heat_on	Sensor internal heating resistor on	0x91
heat_off	Sensor internal heating resistor off	0x92
soft reset	Reset the entire sensor, load E^2PROM data to registers, and restore other registers to their initial values on power-up	0x6A

break	Stop cycle measurement mode	0x93
read scratchpad	Read the scratch area	0xBE
write config	Setting the config area	0x4E
read scratchpad extension	Read the scratch extended region	0xDD
write scratchpad extension	Setting up the scratch extension area	0x77
copy page	Save register data to E^2PROM	0x48
recall page	Load E^2PROM Data to Registers	0xB6
recall EE	Load all 32 bytes of E^2PROM data into registers	0xB8

11. 1-Wire Bus System

1-wire bus systems use a single signal line with a master controlling one or more slave devices. Sensors are always slaves. When there is only one slave device on the bus, the system is referred to as a "single-point" system; when there are multiple slave devices on the bus, it is referred to as a "multipoint" system. All data and command transfers on a 1-wire bus start at the lowest bit. The following description of a 1-wire system is divided into three topics: hardware configuration, transmission sequences, and 1-wire signaling (signal types and timing).

11.1 Hardware Configuration

By definition, a 1-wire bus has only one data line. Each device (master or slave) is connected to the data line through an open-drain or tri-state port. This allows the device to "free" the data line when no data is being transferred, thus making the bus available to other devices.
The internal equivalent circuit of the sensor's 1-wire bus port (DQ pin) is an open drain, as shown in Figure 11.1. The 1-wire bus requires an external pull-up resistor of approximately 4.7 kΩ so that the idle state of the 1-wire bus is high. If for any reason the transmission needs to be paused, the bus must remain idle until the transmission has returned. During recovery, the recovery time between data bits can be infinitely long as long as the 1-wire bus remains in the inactive (high) state. If the bus is pulled low for more than 480 μs, all devices hanging on the bus will be reset.

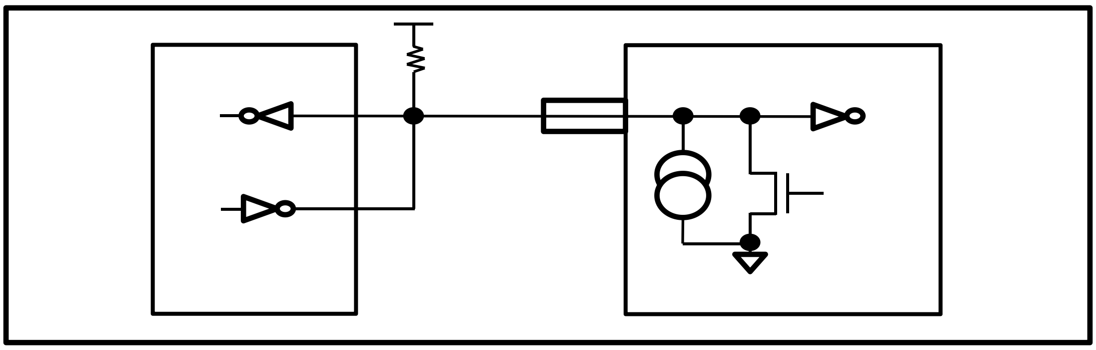


Figure 11.1 1-wire bus hardware configuration

11.2 Transaction Sequences

The transmission sequence for accessing the sensor is as follows:

Step 1 Initialization
Step 2 ROM command (follows any necessary data exchange)
Step 3 Sensor function command (following any necessary data exchange)

It is important to ensure this sequence every time the sensor is accessed, as any steps missing or out of sequence will result in the sensor not responding. The only exceptions to this are the Search ROM [F0h] and Alarm Search [ECh] commands. When these ROM commands are issued, the host must return to step 1 in the sequence.

11.3 Initialization

All execution (processing) over a 1-wire bus begins with an initialization sequence. The initialization sequence consists of a reset pulse issued by the bus controller followed by a presence pulse issued by the slave. The presence pulse lets the bus host know that the slave device is on the bus and ready to operate. The timing of the reset and presence pulses is detailed in the 1-wire bus Signal Timing section.

11.4 ROM Commands

When the bus host detects the presence of a pulse, it can issue ROM commands. These commands operate on a unique 64-bit ROM code for each slave device and allow the host to address specific slaves individually if there are multiple slaves hooked up to a 1-wire bus. These commands also allow the host to determine how many of what type of devices are on the bus and whether any of the devices meet the alarm conditions. There are five ROM commands, each 8 bits long. The master must issue an appropriate ROM commandcommand before issuing a function command for the sensor.

SEARCH ROM [F0h]

When a system is initialized and powered up, the host must identify the ROM codes of all slave devices on the bus so that the host can determine the number and type of slave devices. The host recognizes the ROM codes through a process of elimination, which requires the host to execute a Search ROM loop (e.g., the Search ROM command follows the data exchange) repeatedly until all slave devices are recognized. If there is only one slave device on the bus, a simple Read ROM (below) command can be used instead of the Search ROM command. After each Search ROM cycle, the bus host can return to step 1 (initial state) of the transfer sequence or follow a function command.

Read ROM [33h]

This command allows the bus host to read the 64-bit ROM code of the sensor. This command can only be used if a single sensor is present on the bus. If there is more than one slave on the bus, a data conflict will occur when all slaves attempt to respond at the same time.

Match ROM [55h]

Matching ROM command, followed by a 64-bit ROM code sequence, allow the bus host to address a specific sensor on a multipoint or single-point bus. Only sensors with an exact match of the 64-bit ROM code sequence will respond to a function command from the master. All other slaves will wait for a reset pulse.

Skip ROM [CCh]

This command allows the host to address all devices on the bus simultaneously without sending any ROM codes. For example, the host can cause all sensors on the bus to perform a temperature conversion at the same time by issuing a Skip ROM command to follow a Convert T [44h] instruction.

Note that the Read Scratchpad [BEh] command can only follow the Skip ROM command when a single slave device is hooked up to the bus. In this case, time can be saved by allowing the master to read the slave device without sending the 64-bit device ROM code. If there is more than one slave device on the bus, a Skip ROM command following a Read Scratchpad command will result in a data conflict because multiple devices will attempt to transmit data at the same time.

Alarm Search [ECh]

The flowchart for this command is the same as Search ROM, however, only sensors that have the alarm flag bit set will respond to this instruction. This command allows the host device to know if any sensor has reached a temperature alarm condition at the most recent temperature transition. After each Alarm Search cycle (e.g., the Alarm Search command follows a data exchange), the bus host can return to Step 1 (Initialization) of the transfer sequence or follow a function command. The Operation-Alarm Signals section explains the operation of the alarm flag bits.

11.5 Function Commands

When a bus host addresses a sensor with which it wishes to communicate using a ROM command, the host can issue one of the sensor's function commands. These instructions allow the host to write or read data from the sensor's staging device, initiate temperature conversions, and understand the power supply mode. The sensor's function commands, described below, are summarized in Table 11.5.

CONVERT TEMPERATURE [44h]

This command initiates a temperature conversion. After the conversion, the collected temperature data is stored in the first two bytes of the temperature register, and then the sensor will enter a low power state. The host can issue a read time slot after the Convert Temperature instruction, and then the sensor will respond with a 0 or 1 to indicate that the temperature conversion is in progress or has completed.

READ TEMPERATURE [BCh]

This command allows the host to read the contents of the temperature value register. The data transfer begins at the lowest bit of byte 0x00 and continues traversing the register until byte 0x02 (the temperature cyclic redundancy verification code) is read. all 3 bytes are read, and the sensor enters low power mode by default.

WRITE SCRATCHPAD [4Eh]

This command allows the host to write up to 7 bytes of data to the sensor register. The data transfer begins at the lowest bit of byte 0x04 and continues traversing the register until the highest bit of byte 0xA. All 7 bytes must be written before the host sends a reset signal or the data may be corrupted. (This means that the host can abort the write at any time with a reset).

READ SCRATCHPAD [BEh]

This command allows the host to read the contents of the Scratch register. The data transfer starts at the lowest bit of byte 0x03 and continues traversing the register until byte 0xB (Scratch Cyclic Redundancy Verification Code) is read. 9 bytes are read and the sensor enters low power mode by default. If only a portion of the data in the register is needed, the host can terminate the read at any time by issuing a reset signal.

WRITE SCRATCH_EXTENSION [77h]

This command allows the host to write up to 10 bytes of data to the sensor register. The data transfer begins at the lowest bit of byte 0xC and continues traversing the register until the highest bit of byte 0x15. All 10 bytes must be written before the host signals a reset or the data may be corrupted. (This means that the host can abort the write at any time with a reset).

READ SCRATCH_EXTENSION [DDh]

This command allows the host to read the contents of the Scratch Extension register. The data transfer begins at the lowest bit of byte 0xC and continues through the register until byte 0x16 (the Scratch Extension Cyclic Redundancy Verification Code) is read. 11 bytes are read and the sensor enters a low power mode by default. If only a portion of the data in the register is needed, the host can terminate the read at any time by issuing a reset signal.

COPY PAGE [48h]

This command copies 16 bytes of data from the register to the E^2PROM (see Table 10.1 for correspondence).

RECALL PAGE [B6h]

This command loads 16 bytes of data from the E^2PROM into the register (see Table 10.1 for correspondence). The host device can follow the RECALL PAGE command by posting consecutive read time slots, and then the sensor indicates the status of the load, transmitting a 0 to indicate that the load is in progress, and a 1 to indicate that the load has ended.

RECALL EE [B8h]

This command loads all 32 bytes of data from the E^2PROM into the register (see Table 10.1 for correspondence). The host device can follow the RECALL EE command by issuing consecutive read time slots, and the sensor will then indicate the status of the load, transmitting a 0 to indicate that the load is in progress, or a 1 to indicate that the load has been completed. This loading operation is performed automatically at power-up, so the sensor will have valid data in its registers immediately after power-up.

Table 11.5 Temperature Sensor Function Command Set

Command	Description	Protocol	Activity on 1-wire bus	Note
Temperature conversion command				
Convert Temperature	Initiate temperature conversion	44h	The sensor transmits the conversion status to the host: if the result of reading the time slot is 0, it is busy; if it is 1, the conversion is finished	
read and write commands				
Read Temperature	Read temperature two bytes + cyclic redundancy check	BCh	Sensor transmits 2 bytes of temperature value + CRC to host computer	
Read Scratchpad	Read all Scratch register contents + cyclic redundancy check	BEh	Sensor transmits 8 bytes + CRC to host computer	(1)
Write	Write Data to Scratch Registers	4Eh	Host transmits 7-byte	(2)

Scratchpad			sensors	
Read scratchpad extension	Read all Scratch extended register contents + cyclic redundancy checksums	DDh	The sensor transmits up to 11 bytes to the host	(1)
Write scratchpad extension	Write Data to Scratch Extended Register Contents	77h	The host transfers 10 bytes of data from the extended staging area to the sensor.	(2)
Break	Stop continuous measurement mode	93h	N/A	
Copy Page	Copy 16 bytes of data from register to E^2PROM	48h	Write E^2PROM time 40ms	
Recall Page	Load 16 bytes of data from E^2PROM to registers	B6h	Sensor transmits call status to host	
Recall EE	Load all 32 bytes of data from E^2PROM to registers	B8h	Sensor transmits call status to host	
Sensor related				
Soft Reset	Reset sensor, load E^2PROM data to registers, restore other registers to initial values at power-up	6Ah	N/A	
Heat_On	Sensor internal heating resistor on	91h	N/A	
Heat_Off	Sensor internal heating resistor off	92h	N/A	

Note 1: The host can interrupt data transmission at any time by issuing a reset signal.
Note 2: All bytes must be written before the reset signal is issued.

11.6 Signal Timing of 1-wire Bus

The sensor uses a strict 1-wire communication protocol to ensure data integrity. The protocol defines several signaling types: Reset Pulse, Presence Pulse, Write 0, Write 1, Read 0, Read 1. With the exception of the Presence Pulse, all signaling is initiated by the bus host.

Initialization program - reset and presence pulse

All communication with a sensor begins with an initialization sequence that consists of a reset pulse from the host following a presence pulse from a sensor. Fig. 11.6- 1 explains this sequence. When a sensor sends a presence pulse in response to a reset pulse, it indicates to the host that it is hooked up to the bus and is ready to operate. During the initialization sequence, the host sends a reset pulse by pulling the 1-wire bus low for at least 480µs. The bus host then releases the bus into receive mode. When the bus is released, a pull-up resistor pulls the bus high. When the sensor detects this rising edge, it waits 15µs to 60µs then issues a presence pulse by pulling the 1-wire bus low for 60µs to 240µs.

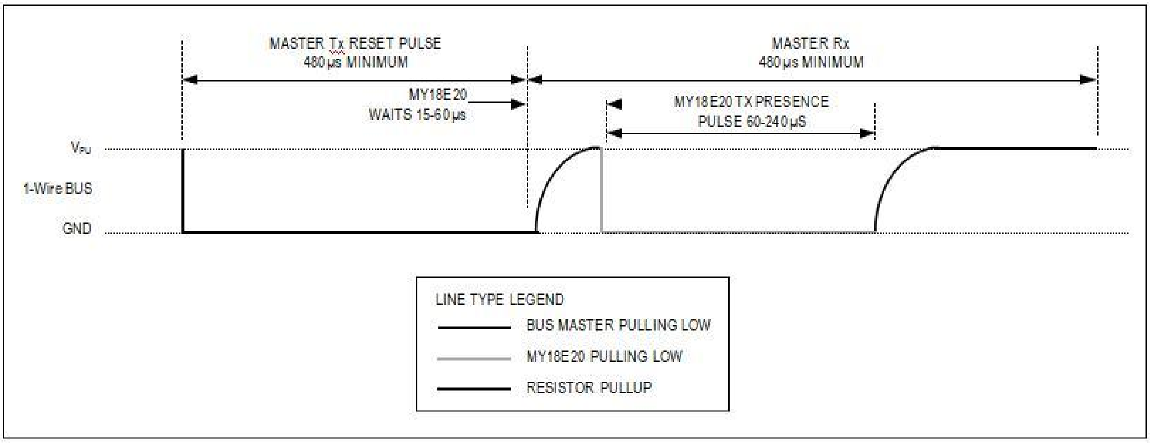


Figure 11.6-1 Initialization Timing

Note: If the sensor supply voltage is 1.75V ~ 1.85V, please note that the reset low level (Reset) is extended to 2000μs in order to ensure stable communication.

Read/Write Time Slot

The bus host writes data to the sensor in write time slots and reads data from the sensor in read time slots. Each time slot transfers one data bit on a 1-wire bus.

Write Time Slot

There are two types of write time slots: "Write 1" time slots and "Write 0" time slots. The bus host writes a logic 1 to the sensor via the write 1 time slot and a logic 0 to the sensor via the write 0 time slot. All write slots must last a minimum of 60μs with a recovery time of at least 1μs between writes. Both write time slots are initiated by the host pulling the 1-wire bus low (see Figure 11.6- 2).

To generate a write 1 time slot, after pulling the 1-wire bus low, the bus host must release the 1-wire bus within 15μs. After the bus is released, the pull-up resistor pulls the bus high. To generate a Write 0 time slot, after pulling the 1-wire bus low, the bus host must keep the bus low continuously (at least 60μs) for the entire time slot period.

The sensor samples a 1-wire bus in a time window of at least 15μs to 60μs after the host initiates a write time slot. If the bus is high during this sampling time window, a 1 is written to the sensor. If the bus is low, a 0 is written to the sensor.

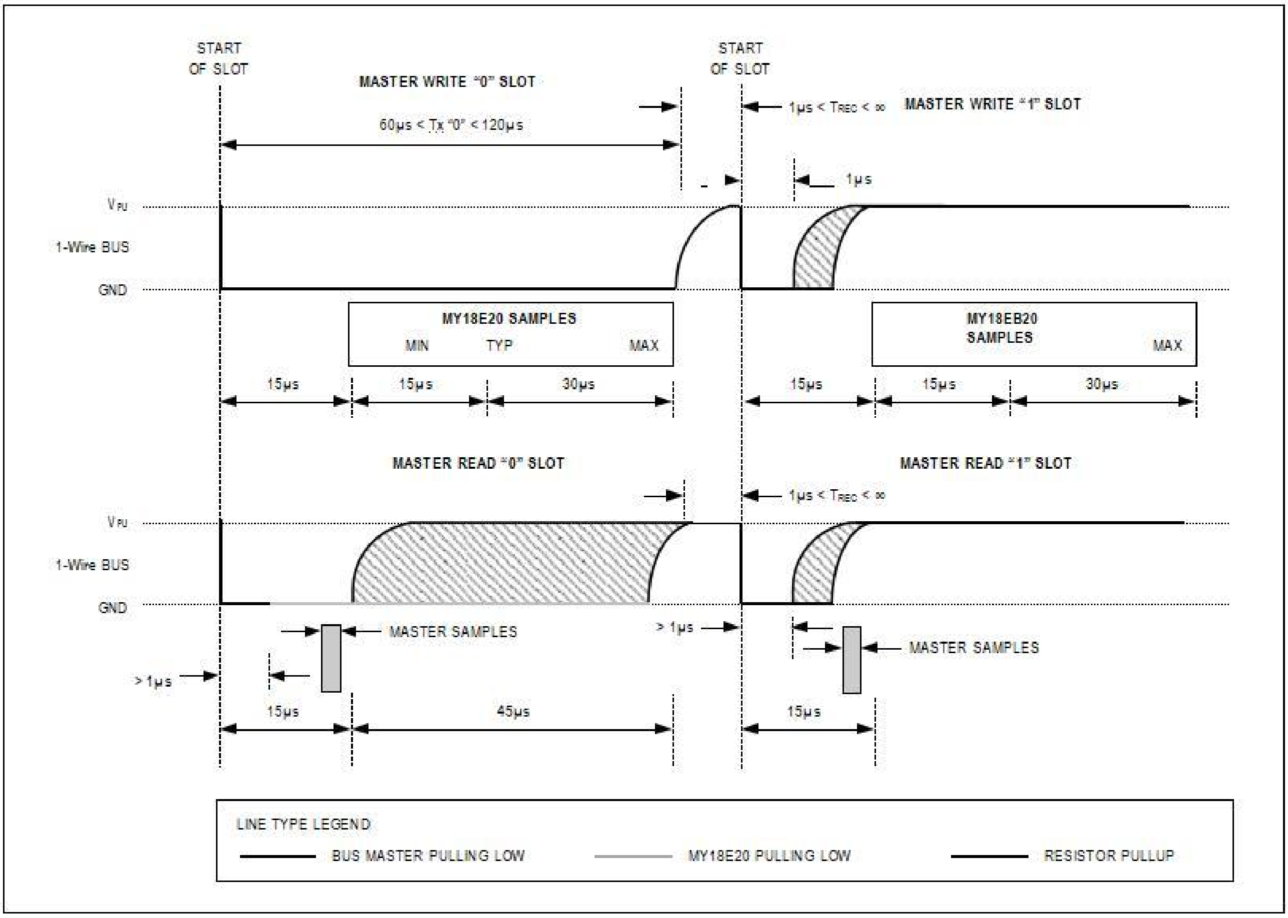


Figure 11.6-2 Read/Write Time Slot Timing

Read Time Slot

The sensor can only transmit data to the host during the time the host issues a Read Scratchpad. All, the host must generate a read time slot immediately after issuing a Read Scratchpad [BEh] command so that the sensor can provide the requested data. Alternatively, the host can generate a read time slot after issuing a Convert T [44h] or Recall EE [B8h] command for operational status. This part of the mechanism is explained in detail in the Sensor Function commands section. All read time slots must last at least 60µs with a recovery time of at least 1µs between writes. read time slots are generated by the host pulling down a 1-wire bus for at least 1µs and then releasing the bus (see Figure 11.6-2). After the host initiates a read time slot, the sensor will begin transmitting either a 1 or a 0 on the bus. the sensor sends a 1 by holding the bus high and a 0 by pulling the bus low. when transmitting a 0, the sensor releases the bus at the end of the time slot, after which the bus is pulled back to the high idle state by the pull-up resistor. The sensor's output data is valid for 15µs after the falling edge of the startup time slot. Therefore, the host must release the bus and sample the bus state within 15µs of the start of the time slot. Figure 11.6-3 illustrates that the sum of t_{INIT} , t_{RC} , and t_{SAMPLE} must be less than 15µs within a read time slot. figure 11.6-4 shows that the system's time margin can be maximized by keeping t_{INT} and t_{RC} as short as possible, and by placing the host sampling time at the end of the 15µs period of the read time slot.

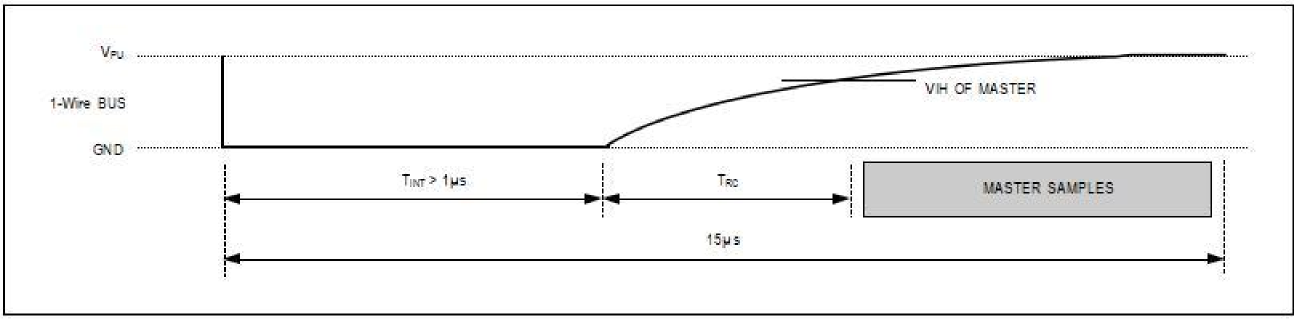


Figure 11.6-3 Detailed Master Read 1 Timing Sequence

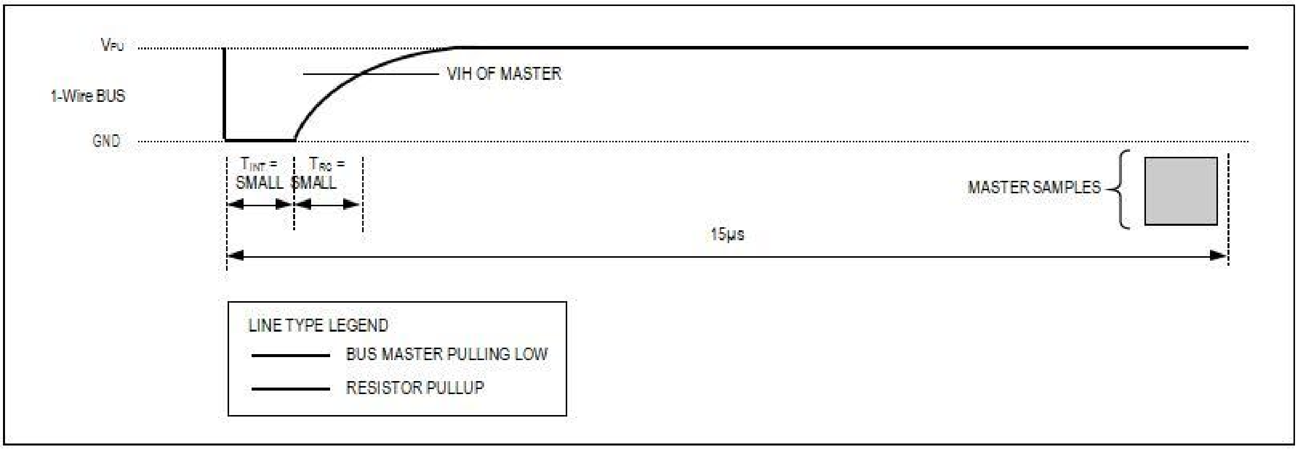


Figure 11.6-4 Recommended Master Read 1 Timing Sequence

11.7 emperature Sensor Operation Example 1

In this example there are multiple sensors on the bus. The bus master reads its buffer after initiating a temperature conversion for a particular sensor and then recalculates the cyclic redundancy checksum to validate the data.

Host mode	Data（MSB)	Description
TX	reset	Host sends reset pulse
RX	presence	The sensor responds by the presence of impulses
TX	55h	Host sends Match ROM command
TX	64-bit ROM encoding	The host sends the sensor's ROM code
TX	44h	Host sends Convert T command
	DQ stays high	Mainframe keeps DQ high during temperature transition times
TX	reset	Host sends reset pulse
RX	presence	The sensor responds by the presence of impulses
TX	55h	Host sends Match ROM command
TX	64-bit ROM encoding	The host sends the sensor's ROM code
TX	BCh	Host sends Read Temperature command
RX	3 data bytes	The master reads the entire register including the cyclic redundancy check. The host then recalculates the cyclic redundancy check of the first 2 bytes of data in the register and compares it to the cyclic redundancy check of the read

		(byte 3). If it matches, the host continues; otherwise, the entire read operation is repeated.

11.8 Temperature Sensor Operation Example 2

In this example there is only one sensor on the bus. The host writes data including Tha_Set_lsb, Tla_Set_lsb, Tha_Set_msb, and Tla_Set_msb to the sensor register. The host then copies the contents of the staging and extended staging registers to the E^2PROM.

Host mode	Data (MSB)	Description
TX	reset	Host sends reset pulse
RX	presence	The sensor responds by the presence of impulses
TX	CCh	Host sends Skip ROM command
TX	4Eh	Host sends Write Scratchpad command
TX	7 bytes	Host sends 7 data bytes to the staging area (including Tha_Set_lsb, Tla_Set_lsb, Tha_Set_msb and Tla_Set_msb-)
TX	reset	Host sends reset pulse
TX	presence	The sensor responds by the presence of impulses
TX	CCh	Host sends Skip ROM command
TX	48h	Host sends Copy Page0 command
TX	DQ stays high	Host keeps DQ high for at least 40ms during copy operation

11.9 1-wire Bus Timing Characterization

Parameters	Symbol	Conditions	MIN	TYP	MAX	Unit
slot length	t_{SLOT}	See Notes	60		120	µs
recovery time	t_{REC}	See Notes	1	5		µs
Write 0 low level time	t_{LOW0}	See Notes	60	60	120	µs
Write 1 low level time	t_{LOW1}	See Notes	1	5	15	µs
Read Data Valid Time	t_{RDV}	See Notes		5	15	µs
Reset Low level Time	t_{RSTL}	See Notes	480	960		µs
Presence detection high level time	tPDHIGH	See Notes	15	30	60	µs
Presence detection low level time	t_{PDLOW}	See Notes	60	115	240	µs

Note: See Figure 11.9 below for more information on time slots.

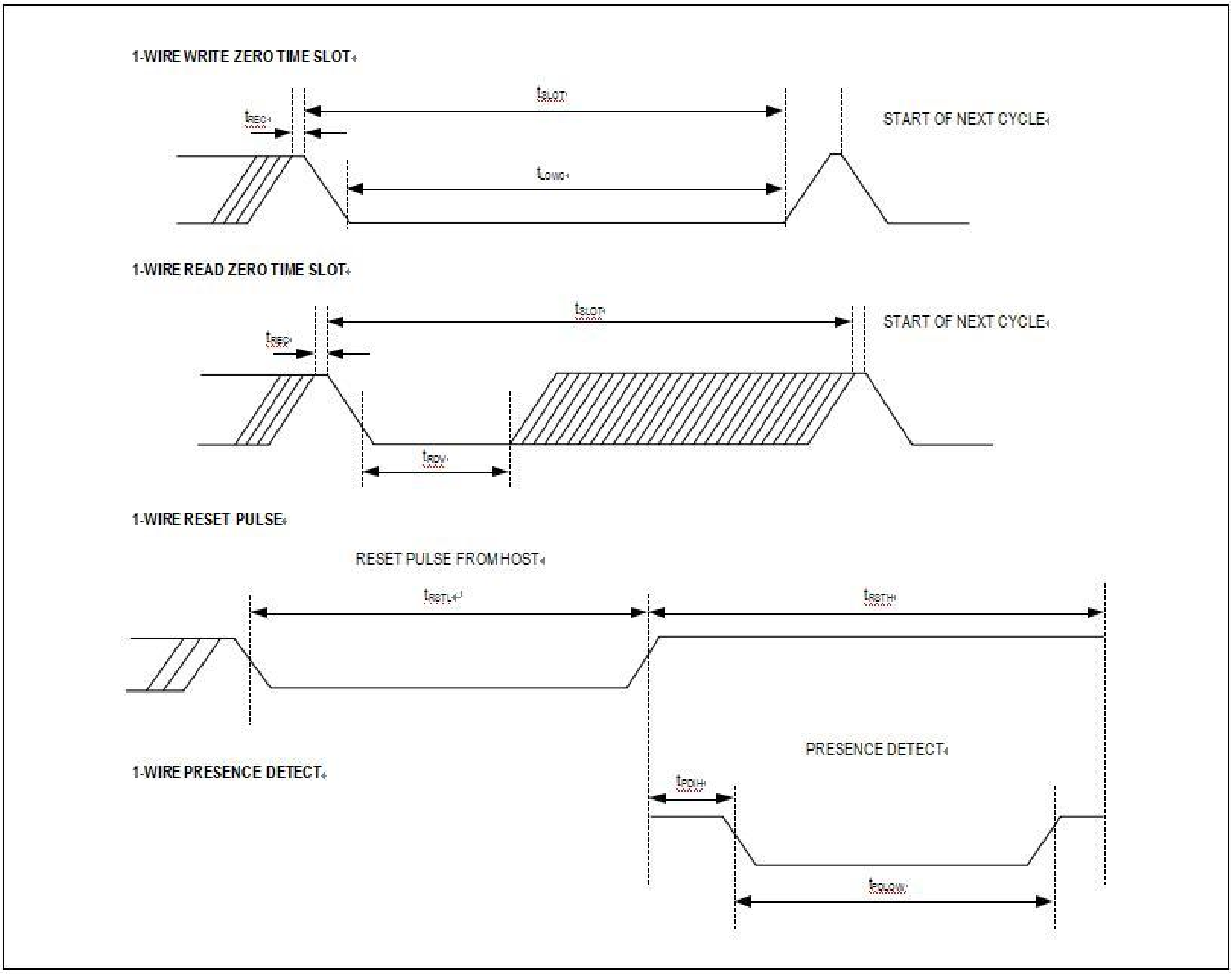
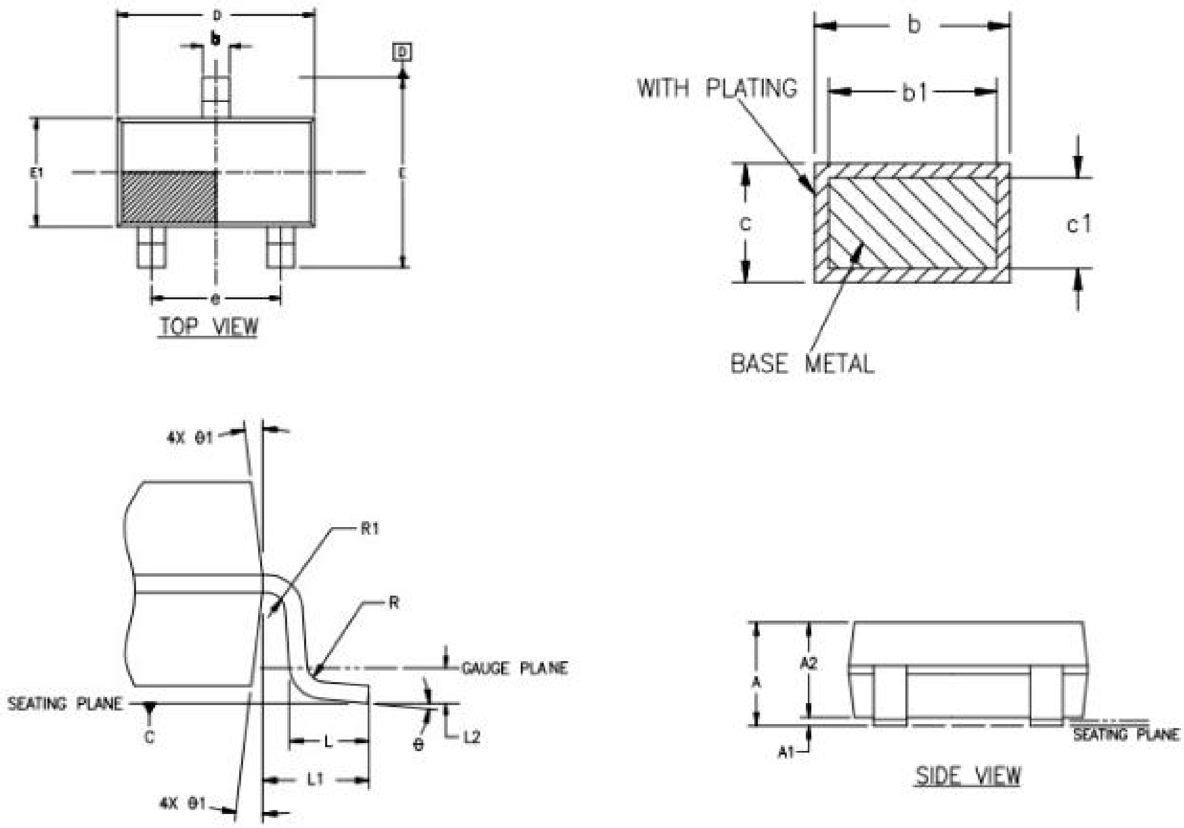


Figure 11.9 Time slot diagram

12. Packaging Diagram



Symbol	Dimensions In Millimeters		
	Min	Nom	Max
A	—	—	1.35
A1	0	—	0.15
A2	1.00	1.10	1.20
b	0.35	—	0.45
b1	0.32	—	0.38
c	0.14	—	0.20
c1	0.14	0.15	0.05
D	2.82	2.92	3.02
E	2.60	2.80	3.00
E1	1.526	1.626	1.726
e	1.80	1.90	2.00
L	0.35	0.45	0.60
L1	0.6REF		
L2	0.25REF		
R	0.10	—	—
R1	0.10	—	0.25
θ	θ°	4°	8°
θ1	5°	10°	15°

Figure 12 Package Drawing of SOT23-3(2.9X2.8X1.1mm)

13. Ordering Information

Part Number	Typical Accuracy	High Precision Temperature Range(℃)	Package Type	Package Qty
T1601Z	±0.1℃	0℃~+50℃	SOT23-3	3K
T1601W	±0.1℃	+20℃~+70℃	SOT23-3	3K
T1601P	±0.1℃	-25℃~+25℃	SOT23-3	3K
T1601B	±0.5℃	0°C~+60°C	SOT23-3	3K