Application Note

Temperature and Humidity Sensor

Version 0.3

June 8, 2015

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1. Overview

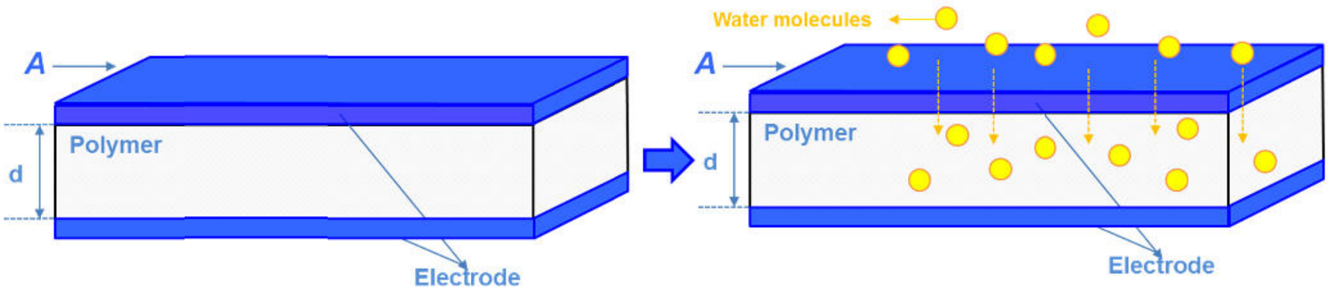
1.1 Introduction

The MXH1100 is a high sensitivity sensor IC with a small package (DFN) for measuring temperature and humidity. This application note describes miscellaneous modes of the MXH1100 sensor IC for detecting temperature and humidity for high volume application. The MXH1100 supports various output modes, that is, there are I^2C, Pulse Width Modulation (PWM), Pulse Density Modulation (PDM), and analog output mode. Each IC is calibrated and tested individually during fabrication. The digital bit depth of MXH1100 can be set by command (8/12 bit up to 12/14 bit for relative humidity/temperature).

1.2 Feature

- Relative humidity sensor with fully calibrated and temperature compensated
- Temperature sensor
- Various selectable outputs
  - I^2C interface & digital output
  - PWM output (humidity/temperature selectable)
  - PDM output (humidity/temperature selectable)
  - Analog output (humidity/temperature selectable)
- Excellent long term stability
- ESD/latch up performance
  - Human body model: ±4000V
  - Machine model: ±200V
  - Charged device model: 750V corner pins, 500V other pins
  - Latch-up: ±100mA

1.3 Electrostatic capacitive type humidity sensor



$$C_{polymer} = \varepsilon_0 \varepsilon_{polymer} \frac{A}{d}$$

$C_{polymer}$ = capacitance of polymer
ε_0 = dielectric constant in free space(F/m)
$\varepsilon_{polymer}$ = dielectric constant of polymer
A = effective dimension of electrode
d = distance between the dielectrics

Figure 1. Principle of capacitive type humidity sensor

The dielectric constant $\varepsilon_{polymer}$ of polymer material varies, when the polymer material absorbs or releases water molecules in the air. The humidity derives from the capacitance variation corresponding to the dielectric constant change of polymer.

1.4 Capacitance to voltage convert

The figure 2 illustrates the capacitance to voltage convert circuit. This circuit is to convert the capacitance which is changed by an external water vapor into the voltage. There are three capacitors and two kinds of switches that operate at the same time. The C_{SENSOR} is a sensing element. The capacitance can be varied by the external water vapor and the range of the capacitance is several hundred fF. The C_{REF} is a capacitor with fixed value inside chips and the function of C_{REF} is to reduce the range of measured capacitance of the C_{SENSOR}. The C_F as a feedback capacitor receives charges from C_{SENSOR} and C_{REF} according to the switch operation. And then the output voltage of amplifier is transferred to the ADC.

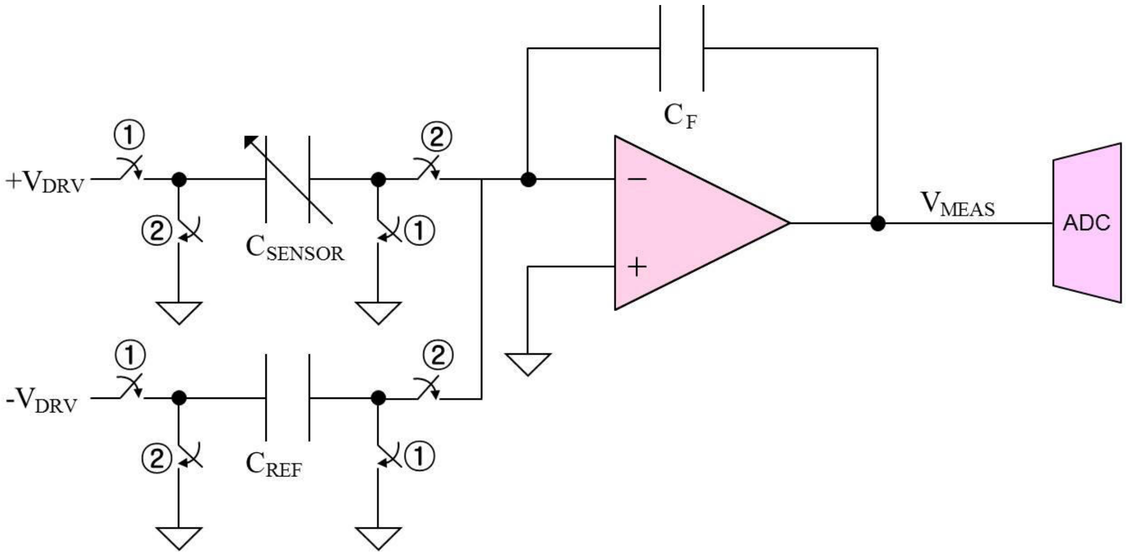


Figure 2. Capacitance to voltage convertor

The figure 3 describes the state of first switch turn on. First of all, each of the first switch and the second switch operates at the same time and the operation of the circuit is as follows:

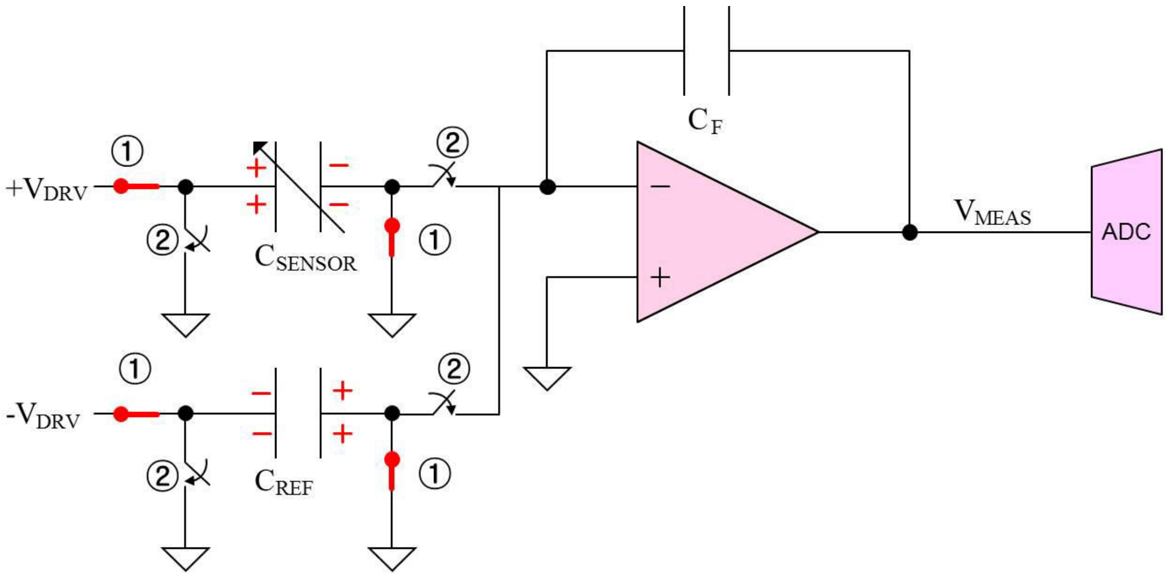


Figure 3. First switch turns on

When the first switches turn on, the positive charges are stored on the left plate of C_{SENSOR} and the negative charges are also stored on the left plate of C_{REF}. The charges in the C_{SENSOR} are finely varied by the external water vapor molecules. The opposite side plates of the each capacitor are charged the opposite polarity.

The figure 4 shows the operation when the second switches are turned on. If each second switch turns on, the left side plate of C_{SENSOR} discharged and the negative charges on the right side of C_{SENSOR} move to the left side of the feedback capacitor C_F. At the same time, the positive charges from C_{REF} move to left side of C_F. The charges in the C_F are sum of C_{SENSOR} and C_{REF}. Since we know capacitance of C_F and V_{DRV}, we can measure the V_{MEAS}. The V_{MEAS} value is transferred to the next block ADC.

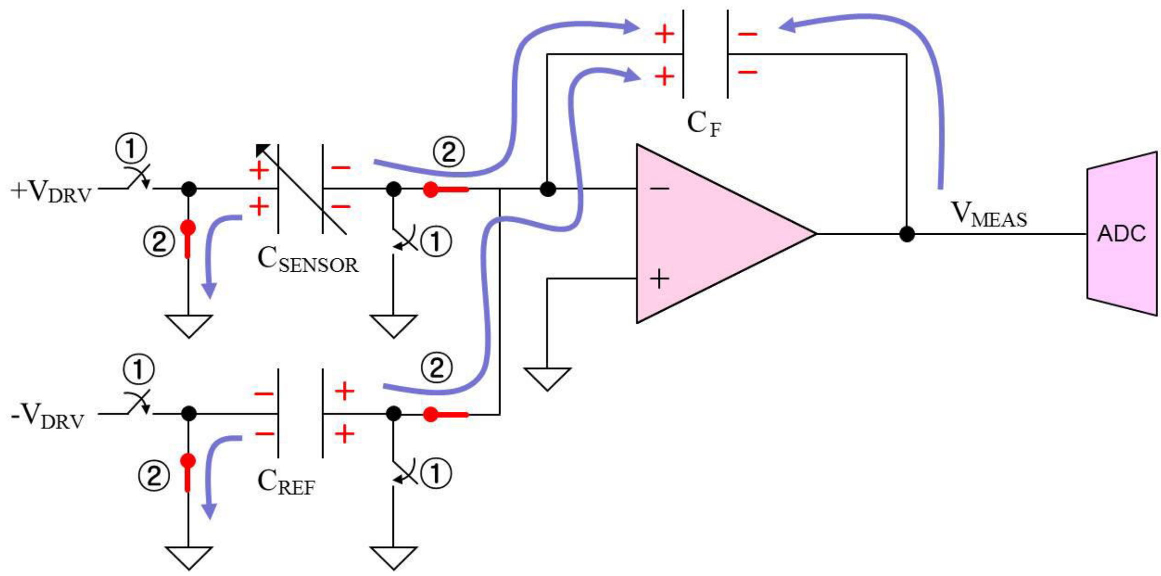


Figure 4. Second switch turns on

The V_{MEAS} output voltage can be expressed by the following equation. Assumed that the electric charge of C_F is Qin, they can be describes as below formula:

$$Qin = -(Csensor * Vdrv - Cref * Vdrv)$$

$$Qin = -(Csensor - Cref) * Vdrv$$

The ratio of the charge Q to the voltage V will give the capacitance value of the capacitor and is therefore given as C = Q/V. This equation can also be re-arranged to voltage for the quantity of charge on the plates as V= Q/C. So we can calculate voltage of V_{MEAS} as below:

$$Vmeas = \frac{1}{Cf}(Csensor - Cref) * Vdrv$$

It means that the V_{MEAS} output value is proportion to the capacitance of C_{SENSOR}.

2. Hardware Configuration

2.1 Pin description

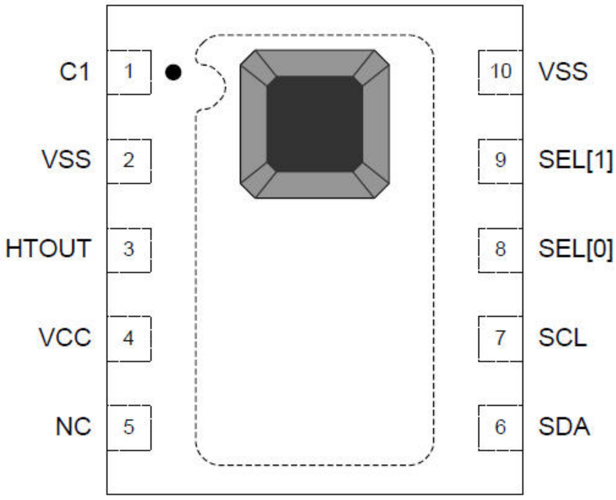


Figure 5. Pin assignment (through view, DFN-10 3.6x2.8)

Pin No.	Pin name	Pin type	Description	Remarks
1	C1	In/Out	Capacitor connection pin for regulated voltage	
2	VSS	GND	Ground	
3	HTOUT	Out	Humidity / temperature voltage output	No connection (PWM,PDM, I^2C mode)
4	VCC	Power	VCC power supply (typical 5V)	
5	NC	NC	No connection	
6	SDA	I/O	I^2C serial data signal & PWM/PDM output	No connection (Analog mode)
7	SCL	I/O	I^2C serial clock signal	
8	SEL[0]	In	Mode selection 0	
9	SEL[1]	In	Mode selection 1	
10	VSS	GND	Ground	
	EP	Exposed pad	EP is electrically connected to ground	

Table 1. Pin description

2.2 Package description

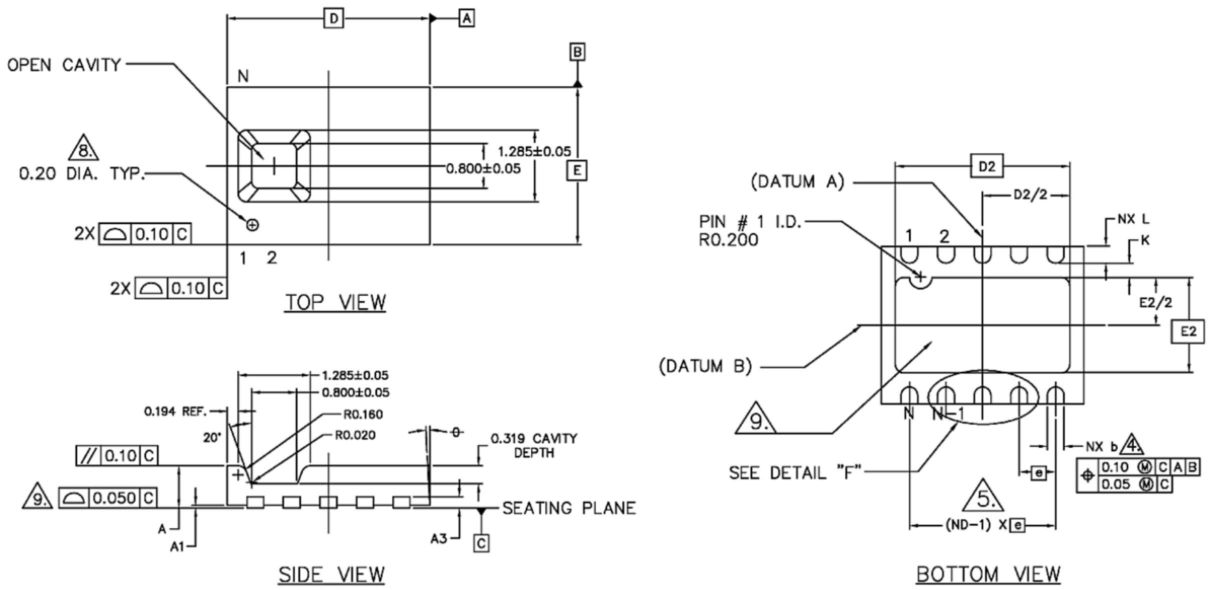


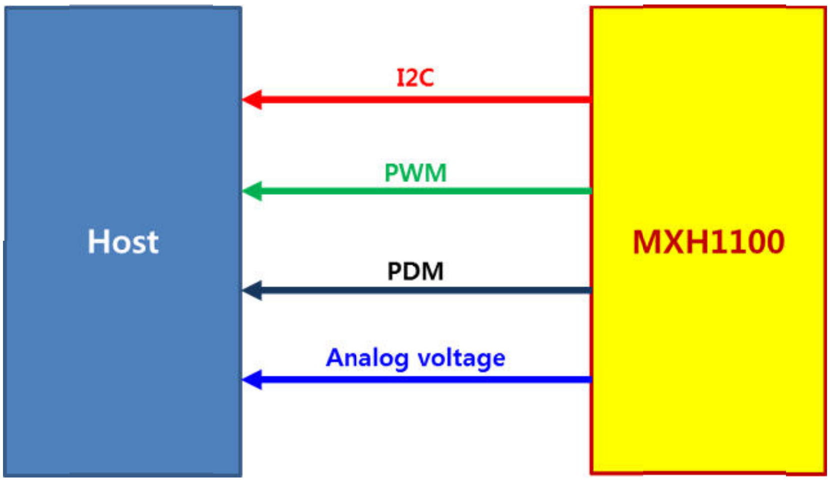
Figure 6. MXH1100 sensor package

SYMBOL	DIMENSIONS			NOTE
	MIN.	NOM.	MAX.	
A	0.70	0.75	0.80	
A1	0.00	0.02	0.05	
A3	0.20 REF.			
b	0.25	0.30	0.35	4
L	0.25	0.30	0.35	
e	0.65 BSC			
N	10			3
ND	5			5
D2	3.00	3.10	3.20	
E2	1.60	1.70	1.80	
D	3.60 BSC			
E	2.80 BSC			
θ	0°	—	—	2
K	0.20	—	—	

All Dimensions are given in millimeters (mm).

Table 2. Package dimension

3. Mode Selection



There are four sensing modes for temperature and humidity on the MXH1100 IC. The modes consist of an analog output mode, a pulse width modulation (PWM) mode, a pulse density modulation (PDM) mode, and I^2C mode. A user has to select just one mode for a specific application.

3.1 Pin setting for mode configuration

The table 3 represents the pin configuration for each mode. The mode setting is realized by the connection of **SEL0** pin **SEL1** pin and **SCL**. There are three usages on the **SDA** pin. The first is for the data port when the MXH1100 is operating with I^2C interface to the host. The second is for the PWM mode output pin. Third is for the PDM mode output pin.

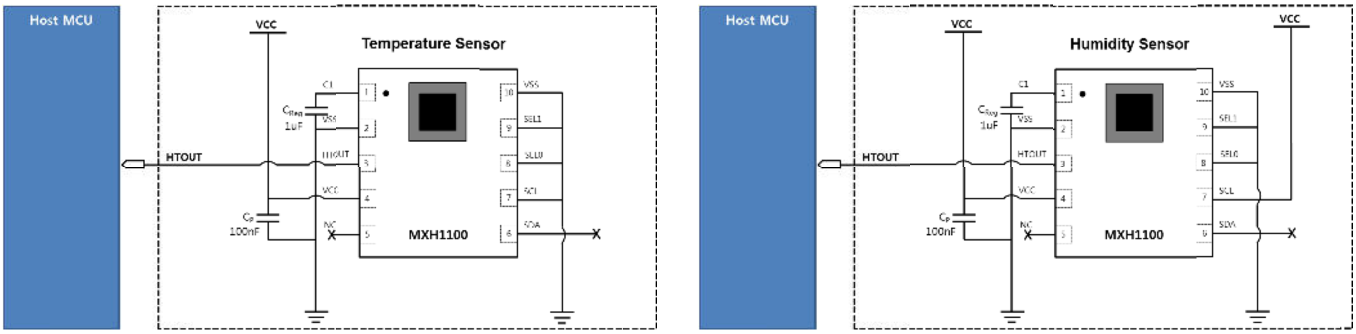
Mode	SEL 1	SEL 0	SCL	SDA(output)	HTOUT
Analog output mode	0	0	0	No connection.	T
	0	0	1	No connection	RH
PWM mode	0	1	0	PWM - T	No connection
	0	1	1	PWM - RH	No connection
PDM mode	1	0	0	PDM - T	No connection
	1	0	1	PDM – RH	No connection
I^2C mode	1	1	Controlled by I^2C		No connection

Table 3. Pin setting condition

3.2 Typical hardware connection

3.2.1 Analog output mode

The MXH1100 supports direct analog output of relative humidity and temperature, respectively. By setting **SEL[1:0]** pins into **'00'**, the analog output is activated. Depending on the state of **SCL** pin, the output state is separated between the temperature and the humidity. That is, if the **SCL** pin is set high state, the output is for humidity. Otherwise, the output is for the temperature. The measuring speed of the sensor is twice per second (2Hz).

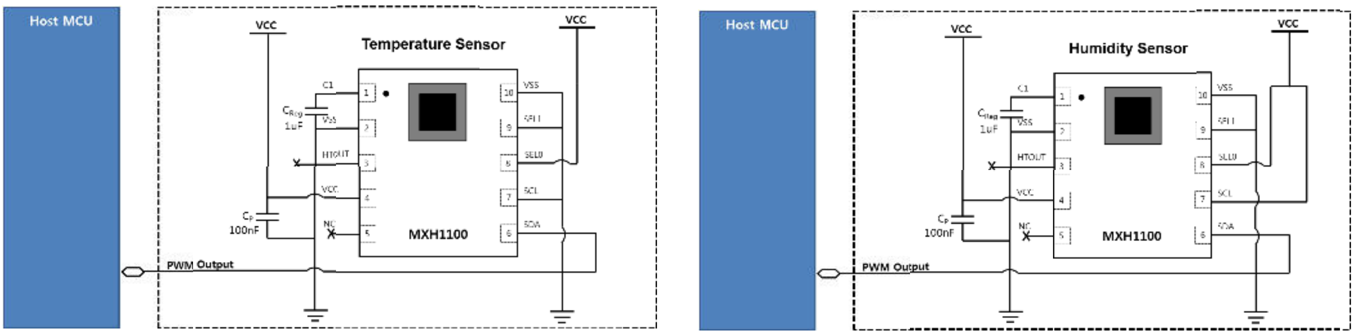


a) Temperature mode b) Humidity mode

Figure 7. Pin connection for analog output mode

3.2.2 PWM mode

The MXH1100 also provides PWM output of relative humidity and temperature, respectively. By setting **SEL[1:0]** pins into **'01'**, the PWM output is activated. Depending on the state of **SCL** pin, the output state is separated between the temperature and the humidity. That is, if the **SCL** pin is set high state, the output is for humidity. Otherwise, the output is for the temperature. The figure 8 illustrates the configuration of each temperature and the humidity mode. And remind that the measuring speed of the sensor is twice per second (2Hz).



a) Temperature mode b) Humidity mode

Figure 8. Pin connection for PWM mode

The PWM output is obtained through the **SDA** pin with running on 120Hz of base frequency. The higher the measured value goes, the larger the duty ratio of PWM signal is output.

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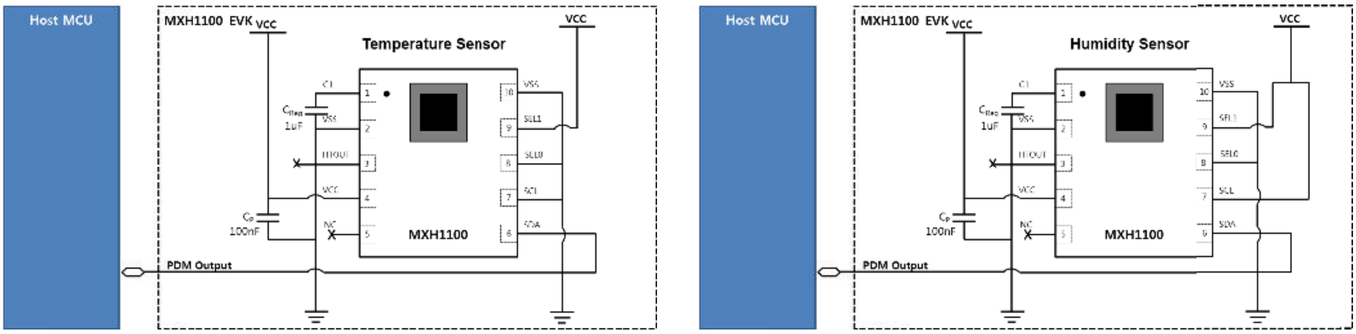
3.2.3 PDM mode

The MXH1100 supports PDM output of relative humidity and temperature respectively. The pulse density modulation (PDM) is a series of pulses. By setting **SEL[1:0]** pins into **'10'**, the PDM output is activated. Depending on the state of **SCL** pin, the output state is separated between the temperature and the humidity. That is, if the **SCL** pin is set high state, the output is for humidity. Otherwise, the output is for the temperature. The figure 9 illustrates the configuration of the PDM modes. The measuring speed of the sensor is twice per second (2Hz) as the same as the other interface mode.



a) Temperature mode   b) Humidity mode

Figure 9. Pin connection for PDM mode

3.2.4 I^{2}C mode

The **SDA** port is used as two purposes according to the **SEL[1:0]** pin setting. The first is for I^{2}C interface data port and the second is using as PWM output port. When the MXH1100 is used to the I^{2}C interface mode, the **SDA** pin is used to transfer data of the sensor. For sending a command to the sensor, the **SDA** is valid on the rising edge of **SCL** and must remain stable, while the **SCL** is in high. After the falling edge of **SCL**, the **SDA** value may be changed.

To prevent signal contention, the host must only drive **SDA** and **SCL** low. External pull-up resistors (e.g. 10kΩ) are required to pull the signal high. For the value of resistance, the bus capacitance should be less than 400pF. It should be noted that the pull-up resistors may be included in I/O circuits of host.

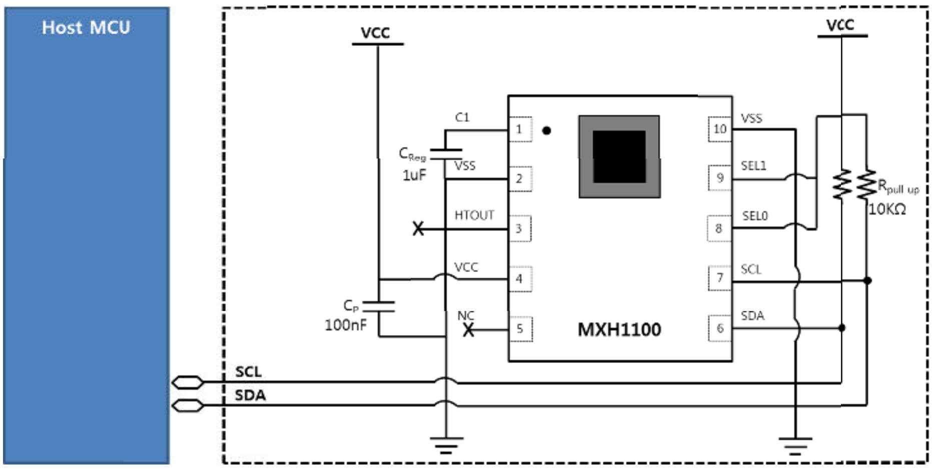


Figure 10. Pin connection for I^{2}C mode

4. Guidelines for PCB Design

The users should design with considering the thermal condition. The heating by external heat source or the sensor itself will reduce the accuracy of temperature and relative humidity measured. To avoid heating of the sensor, please consider the following:

- Remove or minimize metal plane close to sensor
- The distance between the heating element and the sensor must be separated as far as possible.

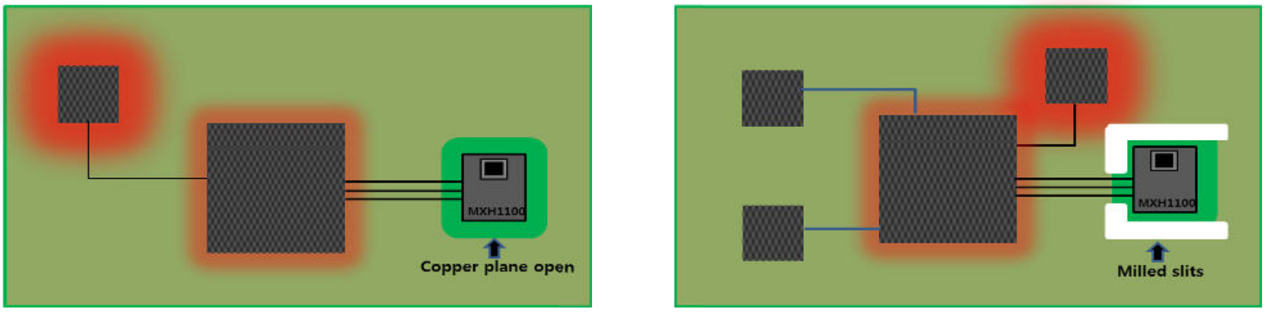


Figure 11. Example of PCB design

As shown in the figure 11, it is possible to minimize the thermal conduction through the method of removing metal near the sensor, if the heating element is keeping a sufficient distance from the sensor. If the heating element is close to the sensor, it is possible to minimize the thermal conduction by adding the slits around the sensor.

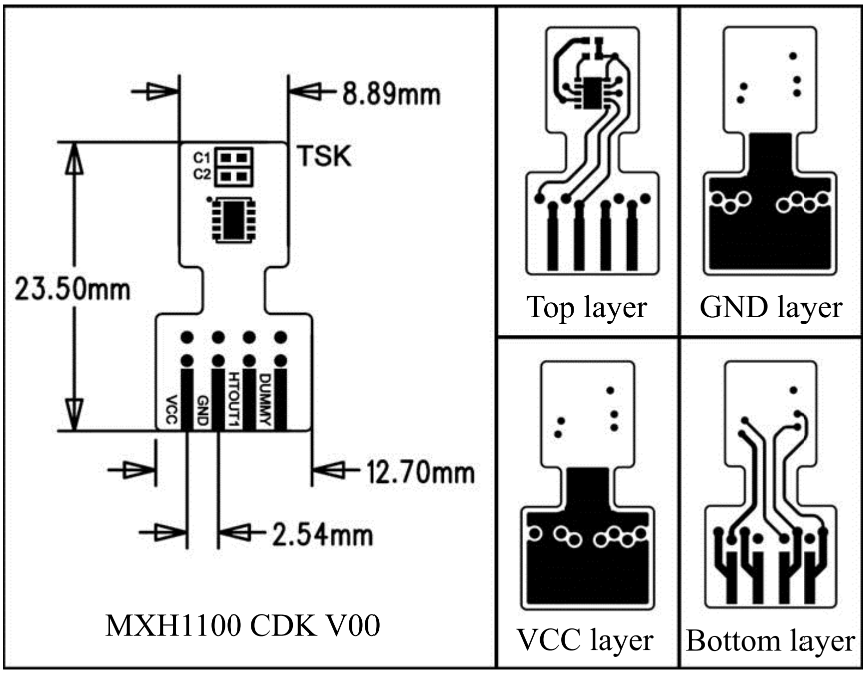


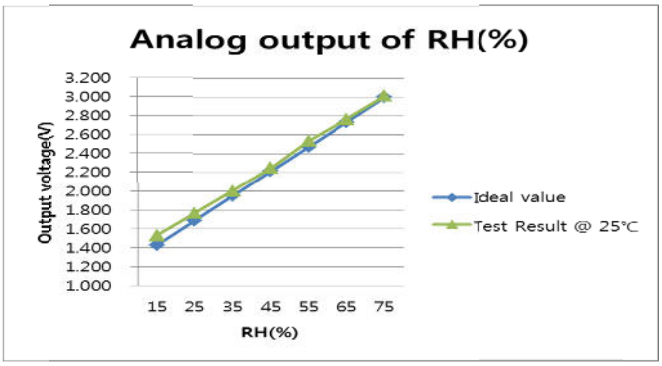
Figure 12. PCB layer structure of MXH1100 CDK

We can provide Customer Development Kit (CDK), and the CDK includes a 4 layer board as shown in the figure 12. To minimize heat conduction, top and bottom layers have only patterns without copper plane. For the same reason, copper plane of inner layers around sensor has been removed also.

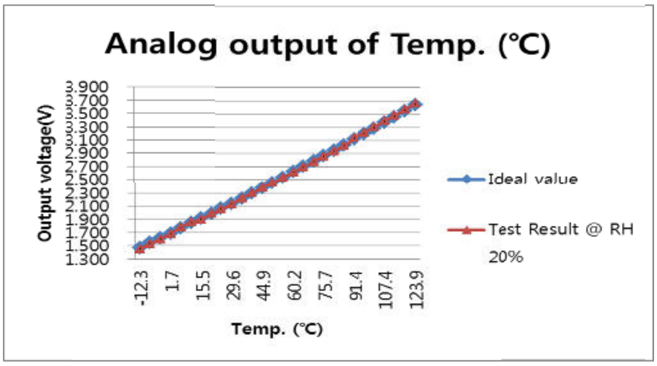
5. Performance Results

5.1 Analog output mode

The figure 13 shows output voltage curve versus a) relative humidity and b) temperature. You can see the measurement fits the ideal value. The values of relative humidity or temperature are obtained by probing the output voltage of HTOUT pin.



a) Raw data of relative humidity



b) Raw data of temperature

Figure 13. Test result

The figure 14 is showing test result of relative humidity in accordance with the temperature change on analog mode. It can be seen that the tolerance of relative humidity is less than 1% in accordance with temperature change, and the tolerance results satisfy the criteria of the specification.

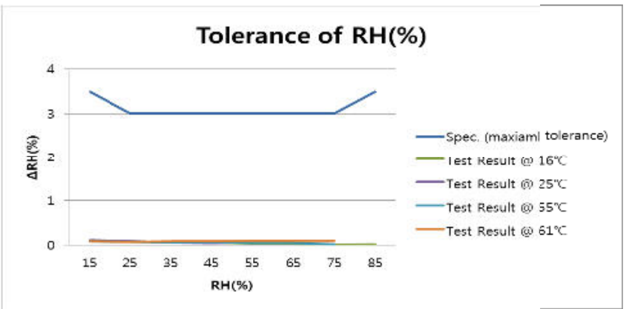


Figure 14. Tolerance of RH by temperature change

The figure 15 shows a ripple result of analog output. The voltage ripple is under 5mV.

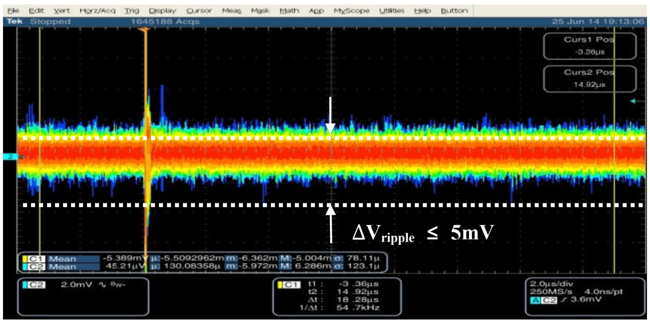


Figure 15. AC ripple of analog output (10uF load condition)

5.2 PWM mode

The relative humidity (RH) and temperature (T) for the PWM mode are calculated by the following formulas:

$$RH = -6 + 125 \cdot T_{PW} / T_F$$

$$T = -46.85 + 175.72 \cdot T_{PW} / T_F$$

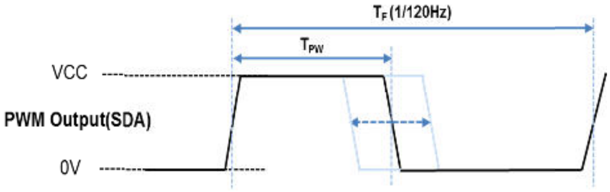


Figure 16. PWM signaling

The figure 17 is showing test results of relative humidity in accordance with the temperature change on the PWM mode. The values of relative humidity or temperature are obtained through the above formulas, which are proportional to the duty ratio of TPW and TF. The vertical axis means the available tolerance of the MXH1100. The tolerance does not exceed the maximal criteria of specification.

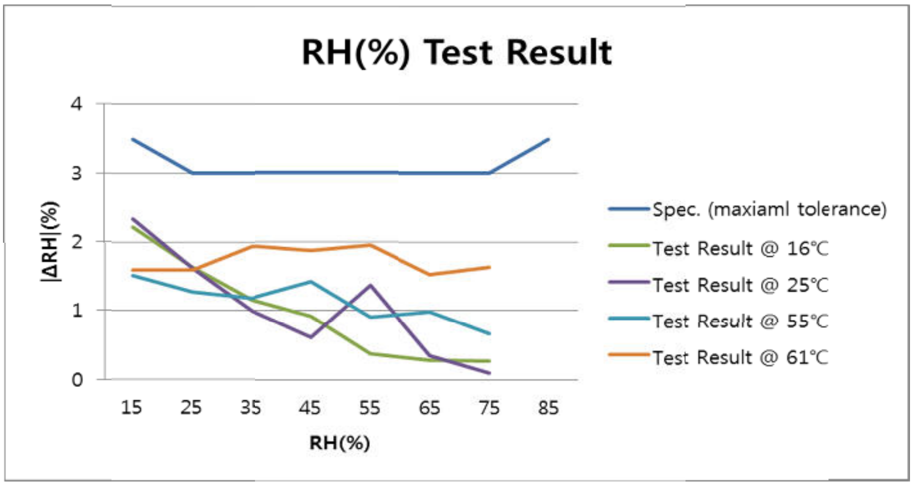


Figure 17. Tolerance of RH by temperature change

5.3 PDM mode

The PDM output is obtained through the SDA pin. In order to demodulate, the PDM signal needs a low pass filter. Therefore, the PDM signal may be converted into an analog voltage corresponding to the measured value. The density of pulses is proportional to the measured value. The figure 18 illustrates the relationship of pulse density modulation.

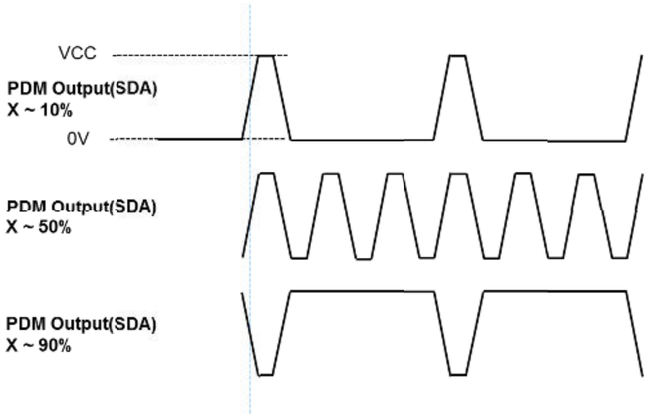


Figure 18. Timing diagram of PDM signal

The figure 19 shows you an example of low pass filter to convert into an analog voltage. The low pass filter consists of a simple RC-filter.

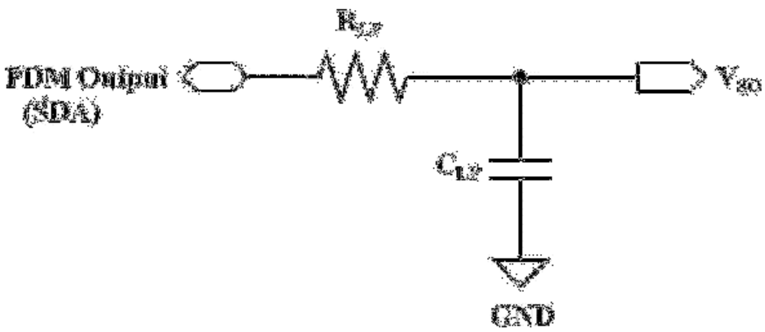


Figure 19. Typical low pass filter for analog output

We'd like to recommend the values of R_{LP} = 100kΩ and C_{LP} = 470nF. When designing the low pass filter, it is very important to minimize the output voltage (V_{SO}) ripple of the low pass filter. Hence, we would prefer that the cut-off frequency of the low pass filter is designed with 3.4Hz. If a larger ripple level is allowed in a certain application, the value of capacitance may be reduced.

If the application is very sensitive to power consumption, the value of resistance may be reduced without complying with the above recommendation.

5.4 I²C mode

The figure 20 is showing test results of relative humidity in accordance with the temperature variation on the I²C mode. It is possible to measure the relative humidity and the temperature by using the UI (user interface program) that is provided with the MXH1100 CDK. The vertical axis represents the deviations of test results between the MXH1100 and a precise relative humidity sensor. The horizontal axis represents the measurement results of the precise relative humidity sensor in accordance with humidity change. The tolerance result does not exceed the maximal criteria of specification.

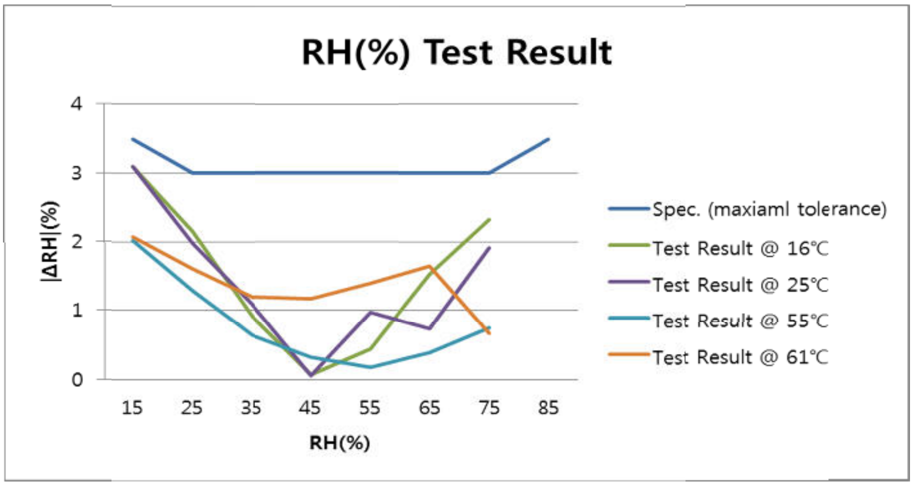


Figure 20. Tolerance of RH by temperature change

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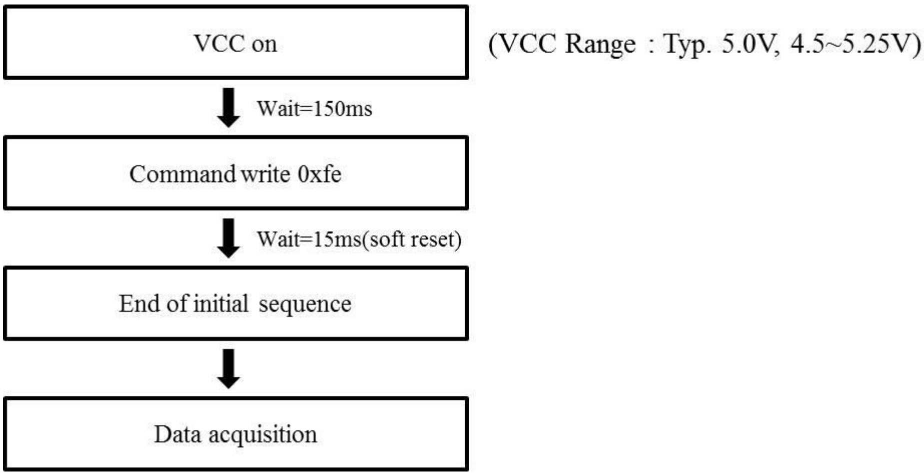
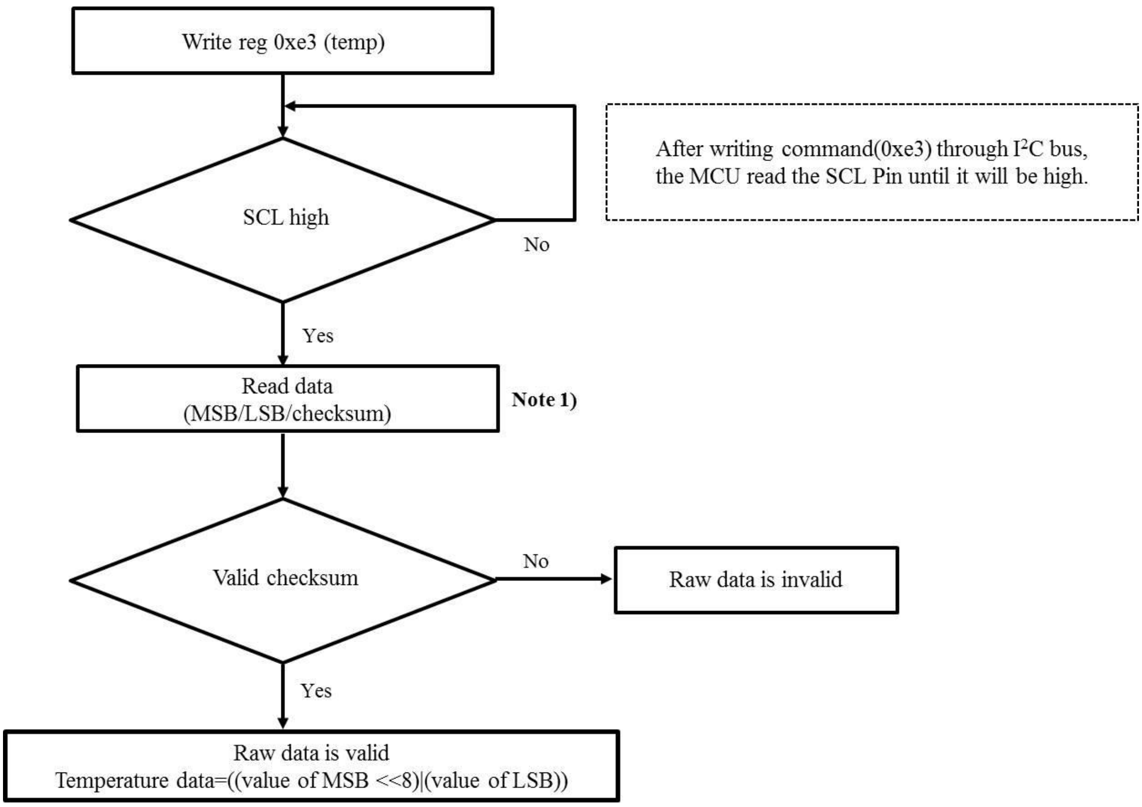
6. I²C Communication Sequence

6.1 Initial sequence



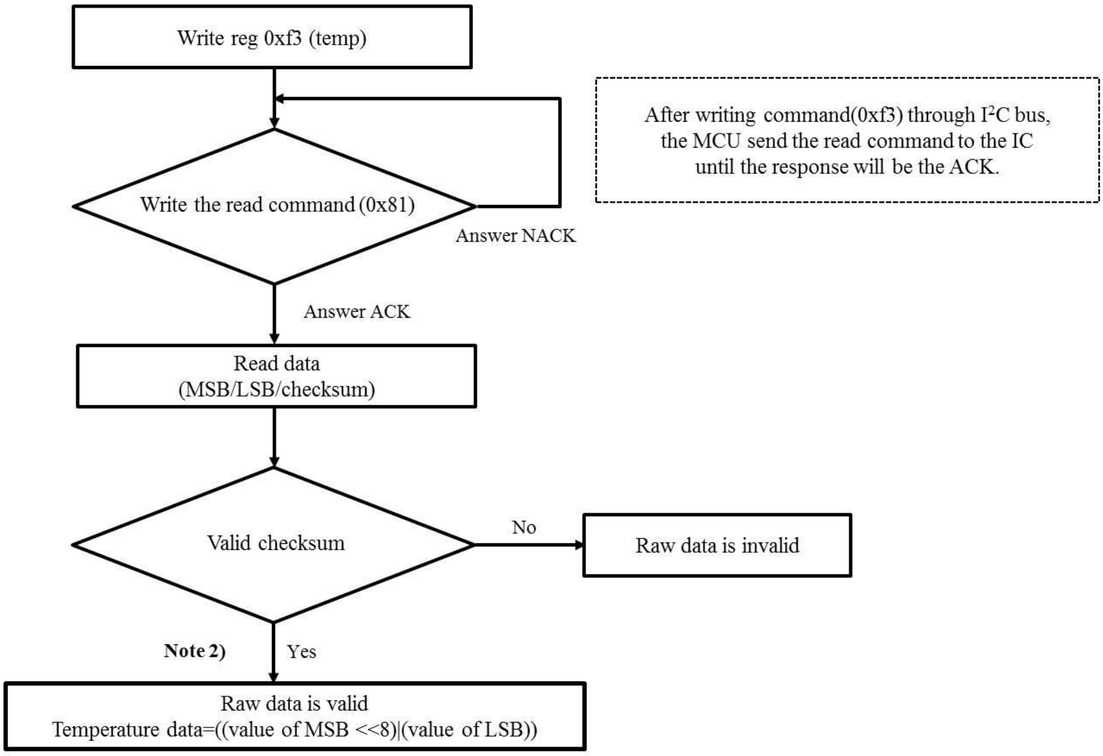
6.2 Hold master mode

There are two different operation modes to communicate with the sensor: hold-master-mode and no-hold-master-mode. In the former case, the **SCL** line is blocked (controlled by sensor) during measurement process. In the latter case, the **SCL** line remains open for other communication, while the sensor is processing the measurement. The no-hold-master mode allows for processing other I²C communication tasks on a bus, while the sensor is measuring.



Note 1) The data reading is finalized by reading the checksum after acquiring the measurement data.

6.3 No hold master mode



Note 2) checksum for success detection. The temperature data is proceeding OR operation of the 8-bit-shifted MSB and LSB.

7. Handling Guidelines

7.1 Storage conditions

The storage condition for MXH1100 is following Moisture Sensitivity Level (MSL) 1. The MSL level 1 defined the storage condition as less than 30 degree and 85% RH with unlimited life-time. But it is recommended to use the sensor within 1 year after date of delivery. The sensor is very sensitive with volatile chemicals such as solvents or other organic compounds. For this reason it is recommended to store in the range of 10 ~ 50°C and 20 ~ 60% RH condition. If you stored at very low temperature before unpacking the sensor from reel package, it should be left on room temperature during sufficient amount of time in order to avoid condensation.

After soldering the humidity sensor on the PCB, it needs strongly careful of treatment. Because the sensor element is very sensitive to volatile contaminants like as vapor of solvent, volatile cleaning agent. Therefore PCBs after soldering process have to be stored in clean air free from contaminations. If contamination is suspected, please inform Magnachip semiconductor.

7.2 Handling guideline

When the sensor element damaged with contamination, the criteria for usage and permissible contamination are determined by correct operation and state of contamination.

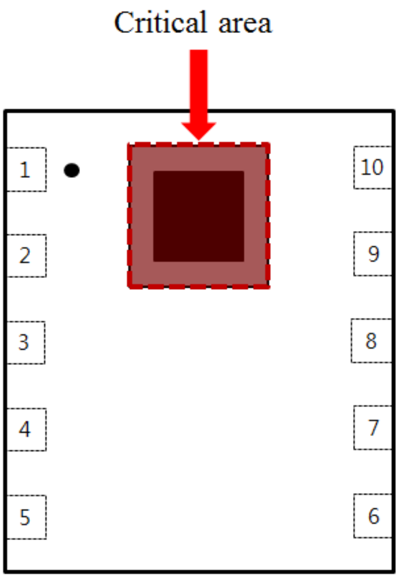
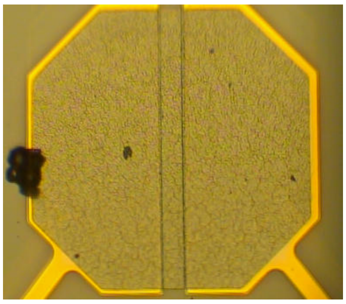


Figure 18. Critical area

The figure 18 shows the critical area of the sensor surface, which must be handled with extreme care to avoid contamination and damages such as flux residue, solder splashes, scratches, fingerprints, etc. Contamination and damage outside of the critical area impair the measurement function only in exceptional cases.

The figure 19 illustrates the contamination of sensor element. The critical area for the sensor is within the open window which contains the active area. It has to be ensured that this area does not come into contact with a handling tool or any other sharp surfaces. Any contamination also has to be avoided.



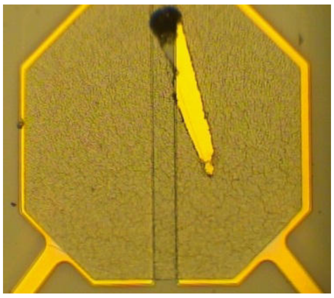


Figure 19. Examples of non-permissible contamination

Please note the following handling guidelines:

- Any damage or contamination of the critical area of the sensor surface should be avoided. Certain contamination like greases, fingerprints, flux, etc is not allowed. This should be considered as well when shipping printed circuit boards (e.g. no damping foam, boards stacked on top of each other, etc).
- Handling systems may only suction-hold the sensors on the backside, on the contact pads, or on the outside edges.
- Loose sitting dust particles are allowed (can be blown off using e.g. oil-free compressed air).
- Slight discolorations in the critical area of the sensor are production conditional and uncritical.
- Remaining soldering flux in other sensor areas is not critical.
- The sensors have to be stored in the original packing reel. It has to be considering that the parts should always be covered with an empty tray or with the top foil. This prevents contamination of the sensors.

7.3 Soldering guide

The figure 20 illustrates reflow temperature soldering profile for Pb-free assembly.

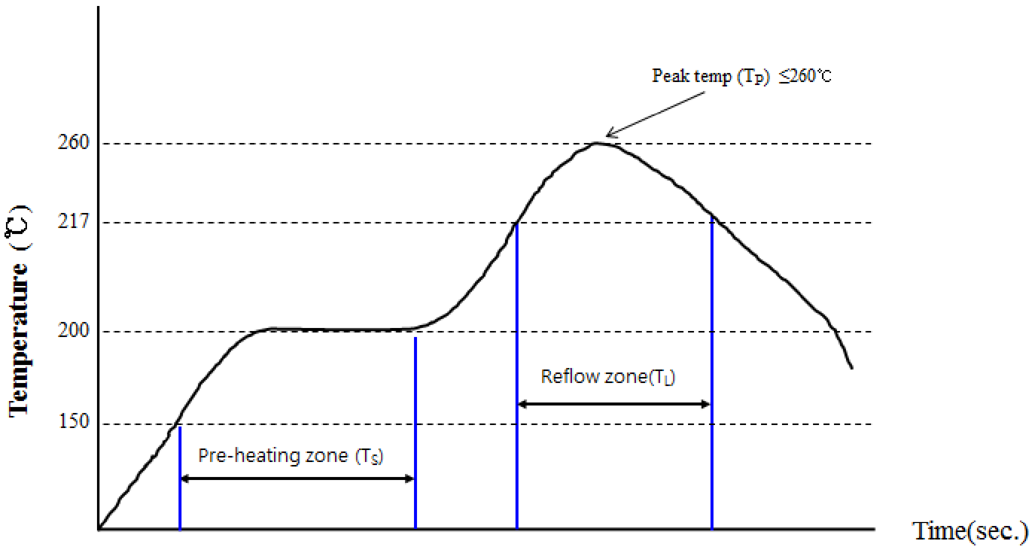


Figure 20. Soldering profile (Pb-free)

The exact profile must be optimized to the corresponding SMD soldering system. Make sure that the peak temperature (T_P) not exceeded the 260°C and should be less than 30 seconds above 255°C. The liquidus temperature is 217°C and time for above T_L not exceeded 150 seconds. And the preheat-zone (T_S) is not allowed to exceed 2 minutes at temperatures between 150°C and 200°C degrees. The maximum ramp up speed (T_L to T_P) is 3°C per seconds and ramp down speed (T_P to T_L) is 6°C per seconds.

7.4 Cleaning

Permitted cleaning method:

- Blowing with oil-free, filtered compressed air, hydrocarbon-free air, or nitrogen
- 30seconds ultrasonic rinse in isopropanol at 23°C (73.4°F)
- Be careful of any contact with the critical area of the sensor

8. Revision History

Version	Issued date	Description of any change	Pages	Revised by
Ver 0.0	2014/6/2	First released	All	KH Kim
Ver 0.1	2014/8/30	Add electrostatic capacitive type sensor	2	KH Kim
		Add remarks in the figure 1	3	
		Add guideline for PCB design	8	
		Add performance results	9-11	
Ver 0.2	2015/4/21	Add ESD and latch up performance	2	SY Kwon
		Add PDM mode	5, 7, 10	
		Add handling guidelines	15-17	
Ver 0.3	2015/6/8	Add Capacitance to voltage convert	3-4	SY Kwon
		Package dimension updated	5	