LAPIS SEMICONDUCTOR

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ML610Q400 Series
Sample Program AP Notes

For
Humidity Calculation Module

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Contents

1. Overview

This document describes the application programming notes (hereafter called the AP notes) arranged to help customers develop software that, by using the RC-ADC, which is hardware that the ML610Q400 Series MCU (hereafter called the MCU) has, performs humidity sensor measurements.

APIs are provided for each function module. The AP notes describe the functions and operating conditions of each API and samples of use of those APIs.

In connection with the AP notes, a sample program is provided that actually operates using APIs. on ML610Q400 Series Demo Kit.
* This AP note also describes about “Celsius Fahrenheit conversion module” that is included in the sample program in the section 3.

◆ Related Documents
The following are the related documents. Read them as required.

・ML610Q400 Series Sample Program AP Notes For Sensor/Mesurement Application
・ML610Q400 Series Sample Program API Manual
・ML610Q431/ML610Q432 User’s Manual
・ML610Q411/ML610Q412/ML610Q415 User’s Manual
・ML610Q421/ML610Q422 User’s Manual
・ML610Q482 User’s Manual
・ML610Q400 Series Demo Kit Hardware User’s Manual
・nX-U8/100 Core Instruction Manual
・MACU8 Assembler Package User’s Manual
・CCU8 User’s Manual
・CCU8 Programming Guide
・CCU8 Language Reference
・DTU8 User’s Manual
・IDEU8 User’s Manual
・uEASE User’s Manual
・uEASE Connection Manual ML610Qxxx
・FWuEASE Flash Writer Host Program User’s Manual
・LCD Image Tool User’s Manual

2. Humidity calculation module

Humidity is measured from the resistor value of humidity sensor. The variable band of resistance value is from several hundred ohm to several mega ohm. Therefore, to fix measurement time, use Resistance Measurement Method 1(*).
And humidity sensor has the temperature characteristics like the figure below. By making use of this characteristics, calculate humidity. First, calculate humidity of 25 degrees centigrade as base, second revise humidity using current temperature.
(*) For detailed description, refer "ML610Q400 Series Sample Program AP Notes For Sensor/Mesurement Application", topic 'How to Measure Resistance Value' of chapter 3.2 RC-ADC Control Module.

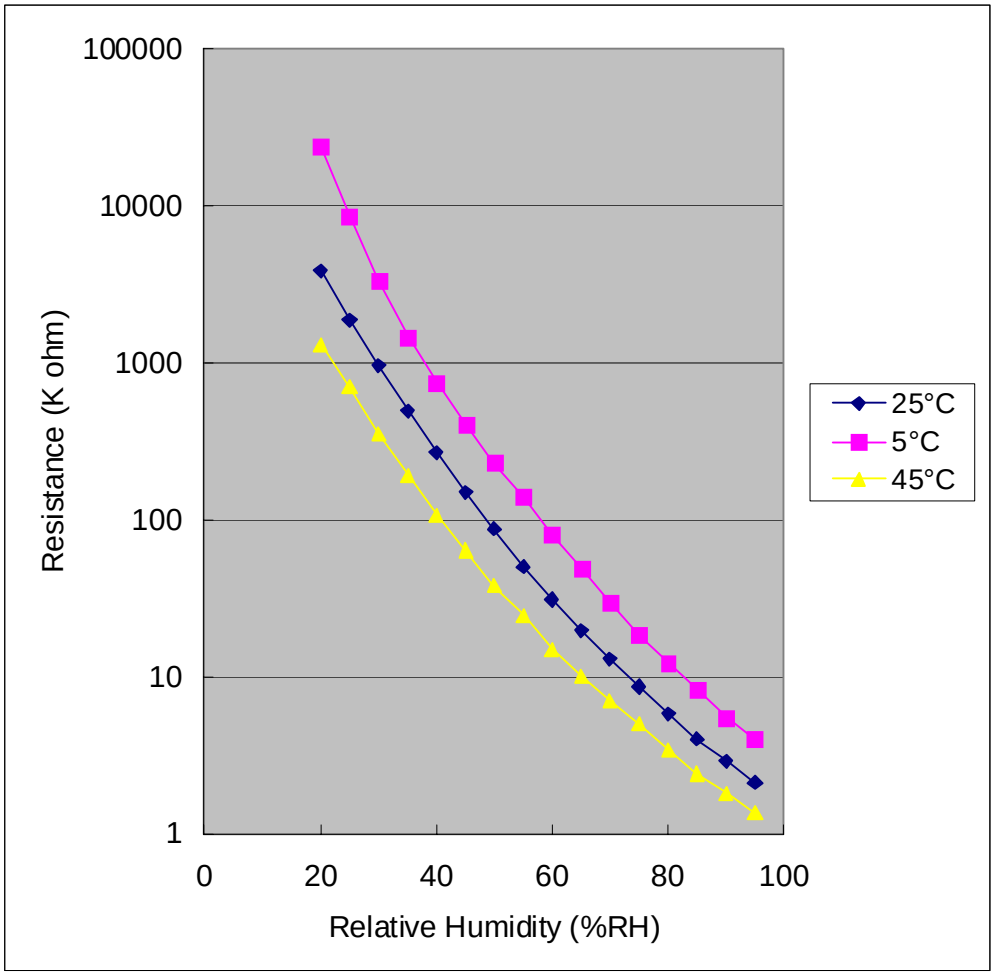


Figure 2-1 The characteristic graph for resistance – humidity (C10-M53R, Shinyei Technology)

%rh	0°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	40°C	45°C	50°C
20	38000	24000	14000	8664	5549	3900	2920	2203	1760	1304	1098
25	14000	8619	5821	3870	2500	1880	1401	1126	852	699	571
30	5012	3367	2251	1615	1248	960	734	579	461	353	294
35	2017	1469	1076	815	649	495	380	322	247	193	160
40	1014	751	583	437	352	270	213	177	135	108	87.5
45	544	406	320	246	191	150	121	98	77.4	63.8	49.9
50	313	230	183	142	112	87	68.7	55.9	44.8	37.8	30.7
55	183	139	111	86.3	66.2	50.2	40.1	33.8	27.6	24.5	19.8
60	104	80.2	62.5	50.4	39.2	31	24.9	19.9	17.5	15	13
65	63.8	49.3	37.8	30.5	24.3	19.8	16.2	13.2	11.7	10.2	8.8
70	38	29.9	23.8	18.9	15.4	13	10.5	9.04	8.04	7.03	6.01
75	23.5	18.4	15.3	12.3	10.3	8.65	7.42	6.37	5.74	5	4.26
80	15.8	12.3	10.2	8.21	7.18	5.8	5.09	4.35	3.93	3.42	3.02
85	10.6	8.32	6.89	5.55	4.82	4	3.49	3.09	2.8	2.41	2.1
90	7.41	5.49	4.85	4.1	3.37	2.9	2.57	2.26	2.04	1.8	1.55
95	5.3	4	3.5	3	2.5	2.11	1.9	1.7	1.5	1.35	1.17

Unit：Kohm

* The data in the shade field is not a standard data.

Figure 2-2 The characteristic table for resistance – humidity (C10-M53R, Shinyei Technology)

First, the measured humidity range, the desired resolution, and the measured state need to be determined. They must be determined by taking the functions and specification of the product that uses the MCU into account. When these are determined, the value of humidity sensor Rh, connected to the microcomputer, the reference resistor Rs and the reference capacitor Cs must be determined. Select a humidity sensor by taking its characteristics and the used environments into account.

The value of Rs is defined by the humidity sensor. In this case of the humidity sensor which the sample program uses, the value of Rs is 150Kohm. For more detail, please see the section "2.6.1. Selection of the reference registor".
You must select enough capacity to gain the required oscillation frequenceis by CR oscillation.

Select Rh, Rs and Cs so that the oscillation frequencies within the measured temperature range can be measured within the specification of the RC-ADC of the MCU. For instance, the following setting is acceptable:

> If V_{DD} = 3 V and Cs = 820 pF, Rh must be 1 kΩ or more.
> If V_{DD} = 1.5 V and Cs = 820 pF, Rh must be 2 K or more.
>
> For detailed description, refer the chapter "RC Oscillation Type A/D Converter" of the User's Manual for your target MCU.

Next, make the conversion table between humidity and humidity-ratio.This humidity-ratio is the ratio of the below two counter value.

a) The number of counter which is gained by the RC oscillation between Rt(humidity sensor) and Cs within base time(This sample program uses 500ms.
b) The number of counter which is gained by RC oscillation between Rs(Base side) and Cs within same base time.

Define each symbol is as follows:
Rh: the resistor of humidity sensor
H: Humidity
frclk: the oscillation frequency by CR oscillation between Rh and Cs
fsclk: the oscillation frequency by CR oscillation between Rs and Cs.

Humidity-ratio (H-ratio) can calculate by frclk/fsclk.
Note:
This sample program multiplies the humidity-ratio by 1024 because of the calculation by an integer.
(If the humidity-ratio is 1024, the humidity is 50% at 25 degrees centigrade because the oscillation frequency of Rh is equivalent to Rs)

The humidity changes by the temperature. For example, although if the humidity-ratio is 1024 at 25 degrees centigrade, the humidity will be 45%, if the temperature is 45 degrees centigrade, the humidity will be approximately 36%.
Similarly, if the temperature is 5 degrees centigrade, the humidity will be 54%.

This sample program calculate the humidity by the below procedure.
① Find the humidity of 25 degrees centigrade.
② If current temperature is lower than 25 degrees centigrade, find the humidity of 5 degrees centigrade.
③ If current temperature is 25 degrees centigrade or higher, find the humidity of 45 degrees centigrade.
④ The difference between the humidity of 5 or 45 degrees centigrade and the humidity of 25 degrees centigrade divided 20 makes the humidity per 1 degree centigrade.
⑤ Find current humidity by the below calculation.
Current humidity = the humidity of 25 degrees + (the difference between current temperature and 25 degrees centigrade * humidity per 1 degree centigrade)

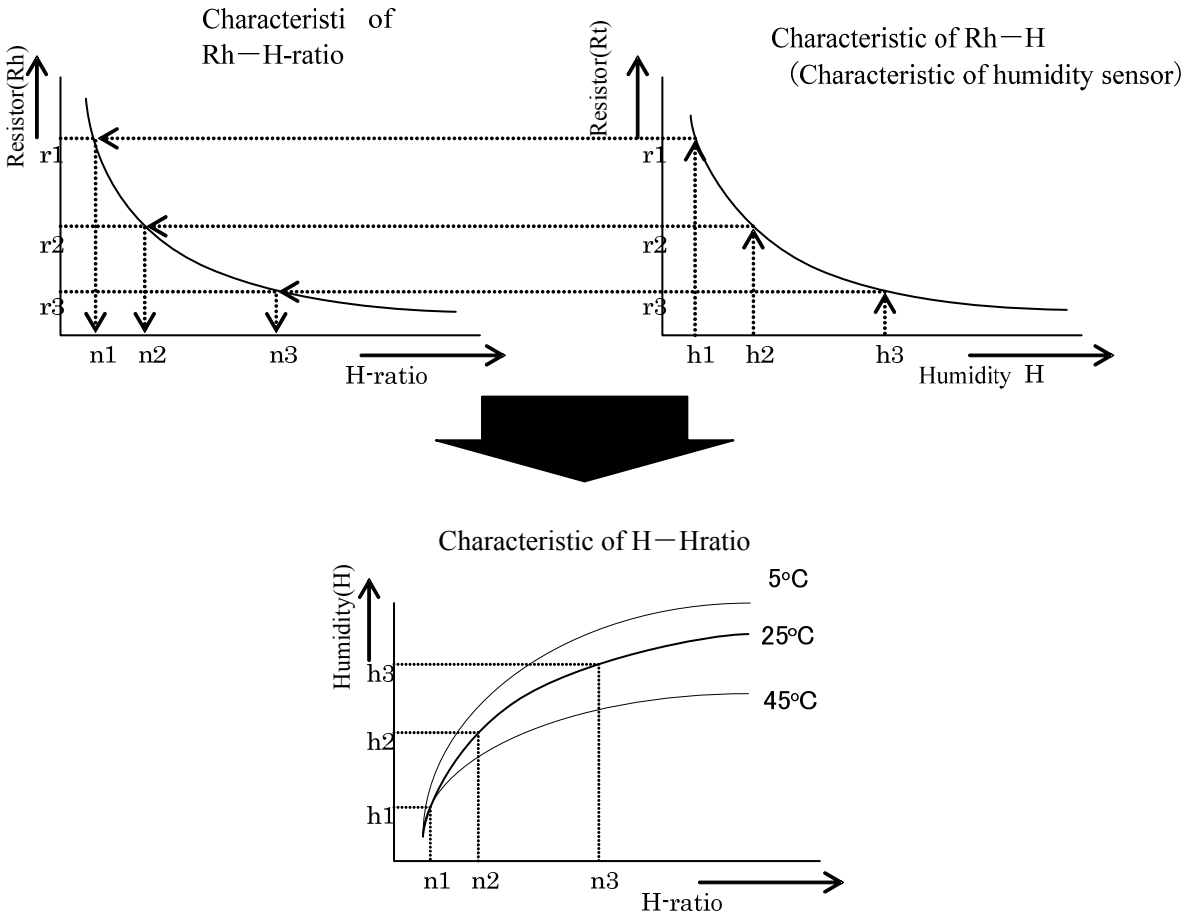


Fig2-3 How to make the characteristic of H-rasio - H

From the Rh-H characteristics, resistance r1 for h1 is obtained. Next, from the Rh– H-rasio characteristics, find n1 (n1 = base count value (@150Kohm)/the count value for r1 * 1024) Similarly, n2 and n3 for h2 and h3, respectively, can be obtained.
The humidity(H)– Humidity ratio (H-ratio) characteristics can be then obtained using the above information.

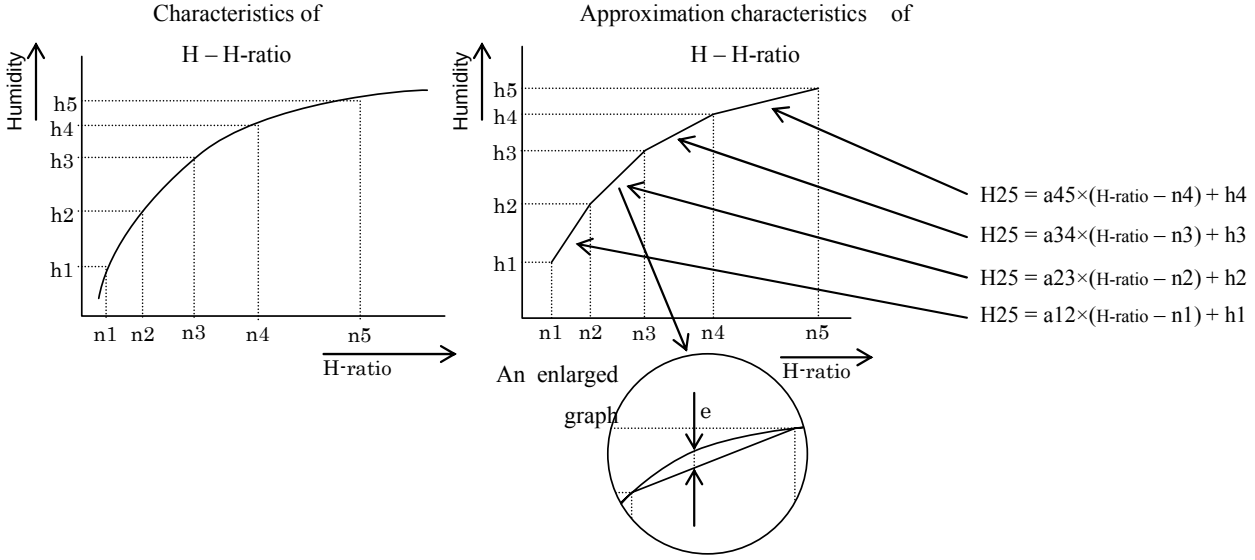
Repeat the above procedure, make the humidity raito table of 25 degrees centigrade, the upper limit table and lower limit table of temperature where the revised calculation is needed. This sample program is using the table for 5 degrees centigrade and 45 degrees centigrade.

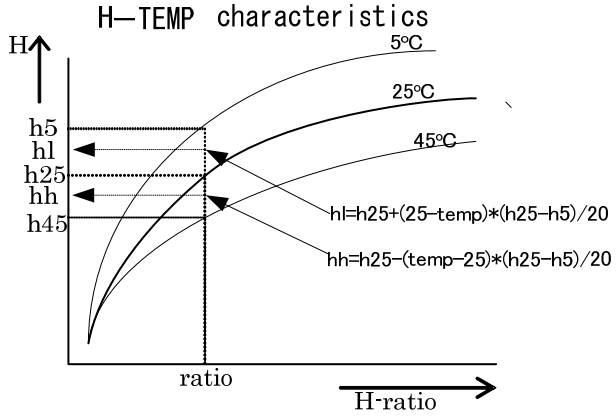
The H-ratio – H characteristics are converted to multiple linear approximation formulas. Moreover store multiple linear approximation formulas to revise humidity at 25 degrees centigrade by temperature in the program. The approximation formula can be made by considering the following:

① The maximum error between the linear approximation and the actual characteristics must be smaller than the desired accuracy.
② The slope of the linear approximation must be less than the desired maximum resolution of temperatures.
③ The linear approximation must be stored within the program area.

The following are examples of linear approximation.

The H– H-ratio characteristics are divided into several intervals (4 portions in this example).
Draw a straight line in each interval as a linear approximation. Linear approximations can be expressed by the following:





Here, the maximum error between the linear approximation and actual characteristics is defined as “e”.
If “e” is larger than the maximum error for measuring humidity, it is necessary to make a finer portion and redo the approximation procedure.

When all the program ROM areas are exhausted because there are too many approximate formulas, reduce the number of approximate formulas by sacrificing accuracy.

The approximate formulas can be input as the ROM table data. The ROM table data are composed of the following 3 items:

・H-ratio
・Slope a(5,25,45 degrees)
・Offset h(5,25,45 degrees)

After finding the humidity using 25 degree’s table, decide applied expression h1 or hh from H-TEMP characteristics.
And calculate the humidity using applied expression.
Determine data length (= number of places) for the desired operation accuracy.

2.1. Function overview

The humidity calculation module calculates the humidity value from the converted result of RC-ADC and measured temperature based on the frequency ratio(that is, humidity ratio) – humidity conversion table of the humidity sensor for C10-M53R made by Shinyei Technology. If you change the humidity sensor, change this conversion table corresponded with the using humidity sensor.

Table2-1 Humidity calculation module API

Function name	Function
humid_calc	Calculate the humidity from the counter value of RC-ADC and temperature.

2.2. Operating conditions

This section describes operating conditions, valid range, restrictions of this module.

-Valid temperature measurement range : 0~50 degrees centigrade (display character '－' of humidity means that temperature is not within 0~50 degrees centigrade)

-Humidity measurement range :20~95%

For the reference resistor Rs, 150K ohm is selected. Its resistance value is the same as the resistance value of the humidity sensor at the condition of temperature 25 degrees centigrade and humidity 45%.
The following table shows the Humidity ratio - Humidity conversion table.

Table.2-1-2 Humidity ratio - Humidity Conversion Table
If you use this table in the program, use the shade field as data.

Table address	Humidity at 25 °C	Humidity ratio		Slope 25 °C	Offset 25 °C		Slope 45 °C	Offset 45 °C		Slope 5 °C	Offset 5 °C
0	105-95	72796		264	99614720		202	91328599		360	111995687
1	95-80	26482		340	83886080		328	76138872		398	93548004
2	80-75	17757		601	78643200		676	70240883		577	88510816
3	74-70	11815		882	73400320		945	64628578		922	83034525
4	69-60	4954		1528	62914560		1469	54547315		1473	72927554
5	59-55	3059	25	2767	57671680	45	2795	49250937	5	2646	67913477
6	54-45	1024	℃	5151	47185920	℃	5227	38609802	℃	5508	56699923
7	44-40	568		11520	41943040		11444	33401393		13322	50637041
8	39-35	310		20275	36700160		19269	28418816		21282	45133928
9	34-30	160		34882	31457280		35107	23142116		36767	39607742
10	29-25	81		66961	26214400		51425	19115612		63104	34666863
11	24-20	39		123894	20971520		123894	13872732		103632	30281395
12	19-18	17		123894	18299932		123894	11201144		188605	26214400
13	17-16	6		123894	16884929		123894	9786141		459052	20971520

2.3. Sample program

The below flowchart explains the procedure of humidity measurement using the humidity calculation module.

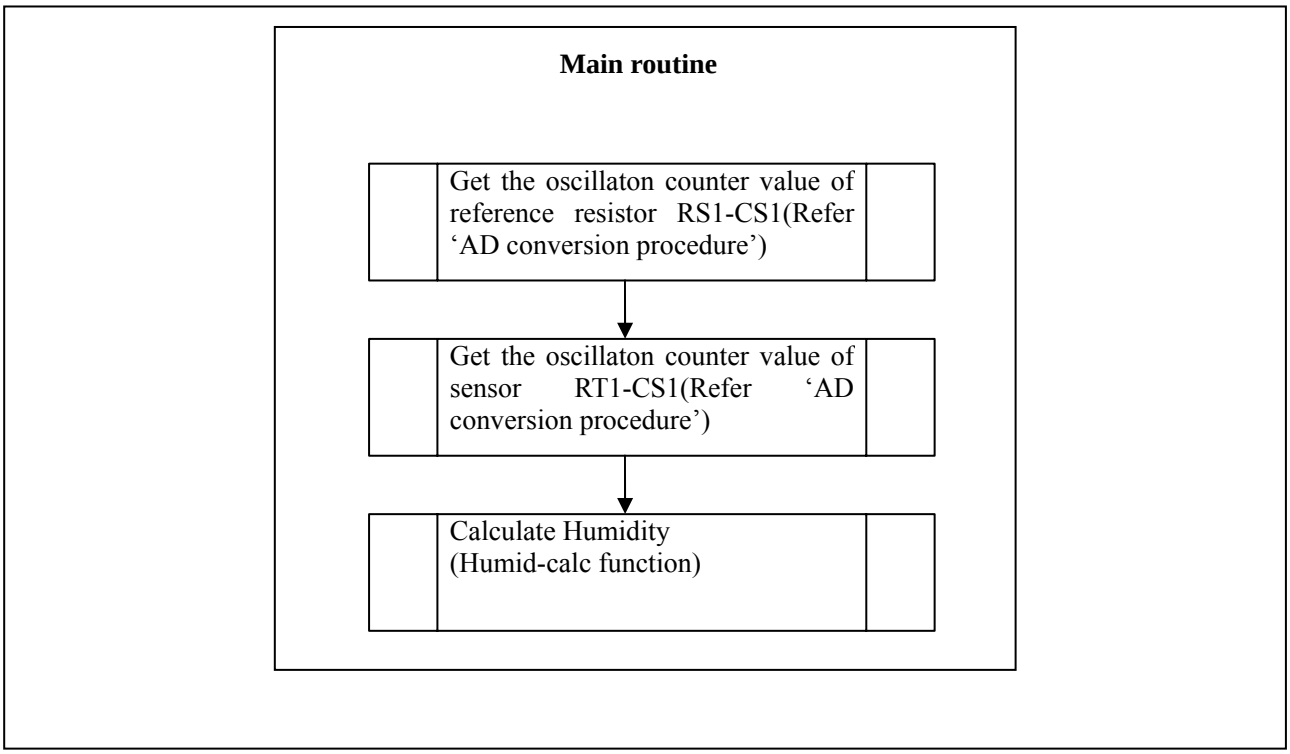


Fig2-4 Procedure of getting humidity

[Main routine]

- Change the circuit for the humidity sensor when the temperature measured.
- If the temperature is not within valid measurement range(50.1 degrees centigrade and up or under 0 degrees centigrade), skip the measurement procedure, and display '- -%'.

1)Get the value of oscillation count for reference resistor RS1-CS1

Get the value of oscillation count for reference resistor RS1-CS1
(value of Counter B)

① Mode of RC oscillation circuit: RS-CS oscillation mode
② Base clock of counter A(BSCLK):LSCLK
③ Setting value of counter A: the base value of oscillation count for reference resistor RS-CS (at interval of 500mS)
④ Setting value of counter B: 0

2)Get the value of oscillation count for sensor RT1-CS1

Get the value of oscillation count for sensor RT1-CS1
(value of Counter B)

① Mode of RC oscillation circuit: RT-CS oscillation mode
② Base clock of counter A(BSCLK):LSCLK
③ Setting value of counter A: the base value of oscillation count for reference resistor RS-CS (at interval of 500mS)
④ Setting value of counter B: 0

3)Humidity calculation

Calculate the value of temperature by **humid_calc function** using the above mentioned oscillation count.

*For detailed procedure, refer "ML610Q400 Series Sample Program AP Notes For Sensor/Mesurement Application" Section 3.2.3.1 A/D Conversion Procedure

[humid_calc]

1) Get a ratio for base value.

2) Calculate the ratio (H_ratio) from the below expression.

H_ratio = (the oscillation count base value of sensor RH-CS / the oscillation count value of sensor RH-CS) × 1024

1024 means the revision for processing the integer calculation. Note that the circuit parameter Rh, Rs and Cs must be selected in advance so that the value of H_ratio can not overflow its range when 1024 is multiplied.

Next, search entries of humidity ratio from address 0 in the Humidity ratio–Humidity conversion table until H_ratio is less than an entry of humidity ratio.

3) Calculate the distance between the searched humidity ratio and H_ratio by the following expression.

RH_distance = H_ratio - (the searched humidity ratio)

4) Calculate the humidity at 25 degrees centigrade (RH25) by using the slope and offset at 25 degrees centigrade (Slope25 and Offset25), which correspond to the searched humidity ratio.

RH25 = (RH_distance × Slope25 + Offset25) >> 20

The value 20 is a multiplier that has already been multiplied to the slope and offset in the Humidity ratio–Humidity conversion table in order to improve calculation accuracy.

5) Calculate the revised humidity RH from current temperature (T).

(a)If current temperature is 25 degrees centigrade and over, calculate the humidity at 45 degrees centigrade (RH45) from the entries of 45 degrees centigrade in the Humidity ratio–Humidity conversion table.

RH45 = (RH_distance × Slope45 + Offset45) >> 20

Calculate the humidity per temperature 1 degree between 25 and 45 degrees centigrade, and multiple it by the difference between current temperature and 25 degrees centigrade, then it is possible to get current humidity. The expression of this operation is as follows:

RH = RH25 - ((RH25 - RH45) / 20) × (T - 25)

(b)If current temperature is less than 25 degrees centigrade, calculate the humidity at 5 degrees centigrade (RH5) from the entries of 5 degrees centigrade in the Humidity ratio–Humidity conversion table.

RH5 = (RH_distance × Slope5 + Offset5) >> 20

Calculate the humidity per temperature 1 degree between 5 and 25 degrees centigrade, and multiple it by the difference between current temperature and 25 degrees centigrade, then it is possible to get current humidity. The expression of this operation is as follows:

RH = RH25 + ((RH5 - RH25) / 20) × (25 - T)

*After calculation, if the humidity is 100% and over, the result becomes 100%.
And if the humidity is 20% and under, the result becomes 20%.

Example:

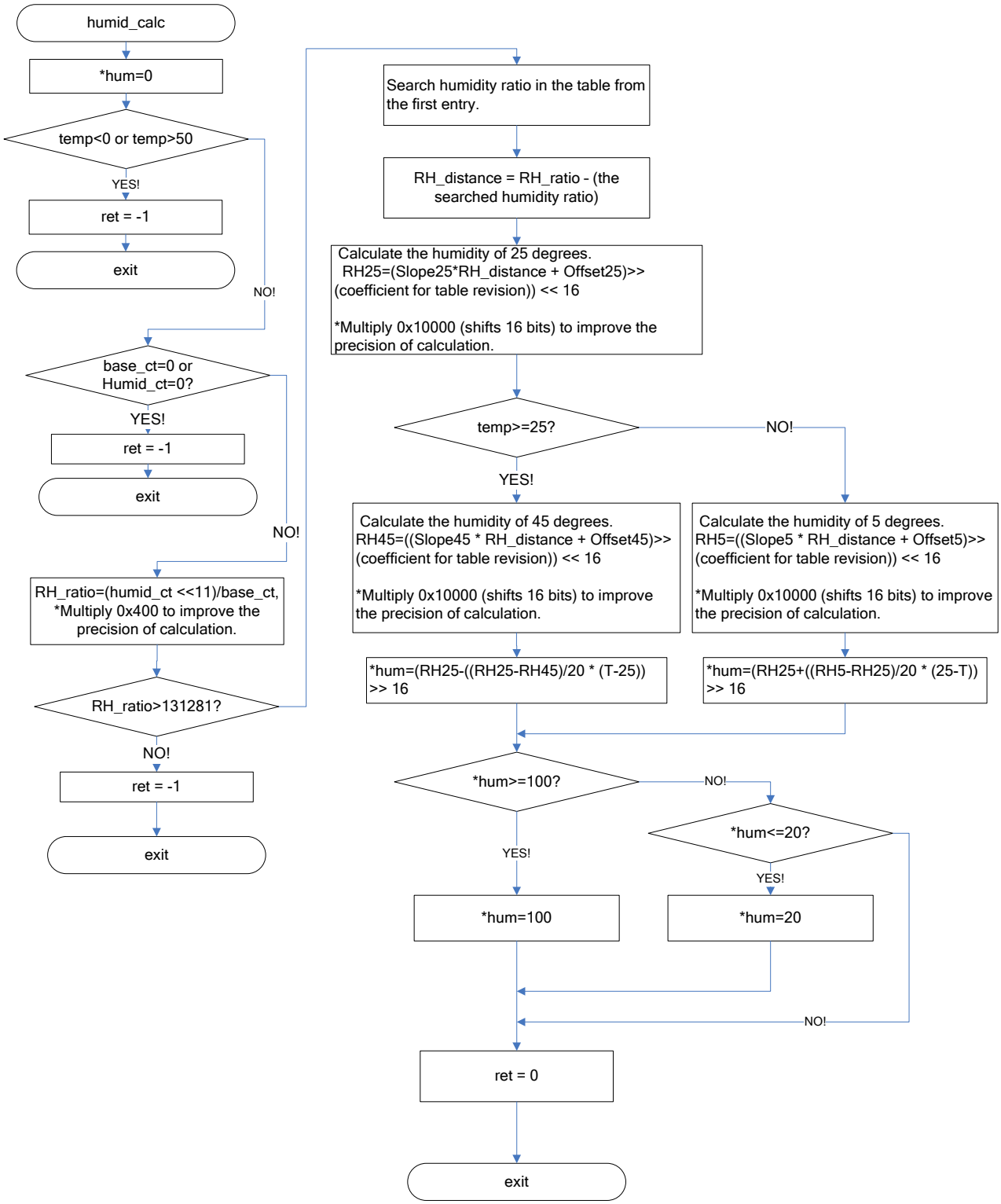
In the case that the temperature is 40 degrees centigrade, a humidity ratio is 4000, it is possible to calculate the humidity by the below procedure. In this case, use table address 5.

□calculate the humidity at 25 degrees centigrade (RH25)
using RH25 = （RH_distance × Slope25 + Offset25） >> 20
RH25 = ((4000 - 3059) × 2767 + 57671680) >> 20 = 57

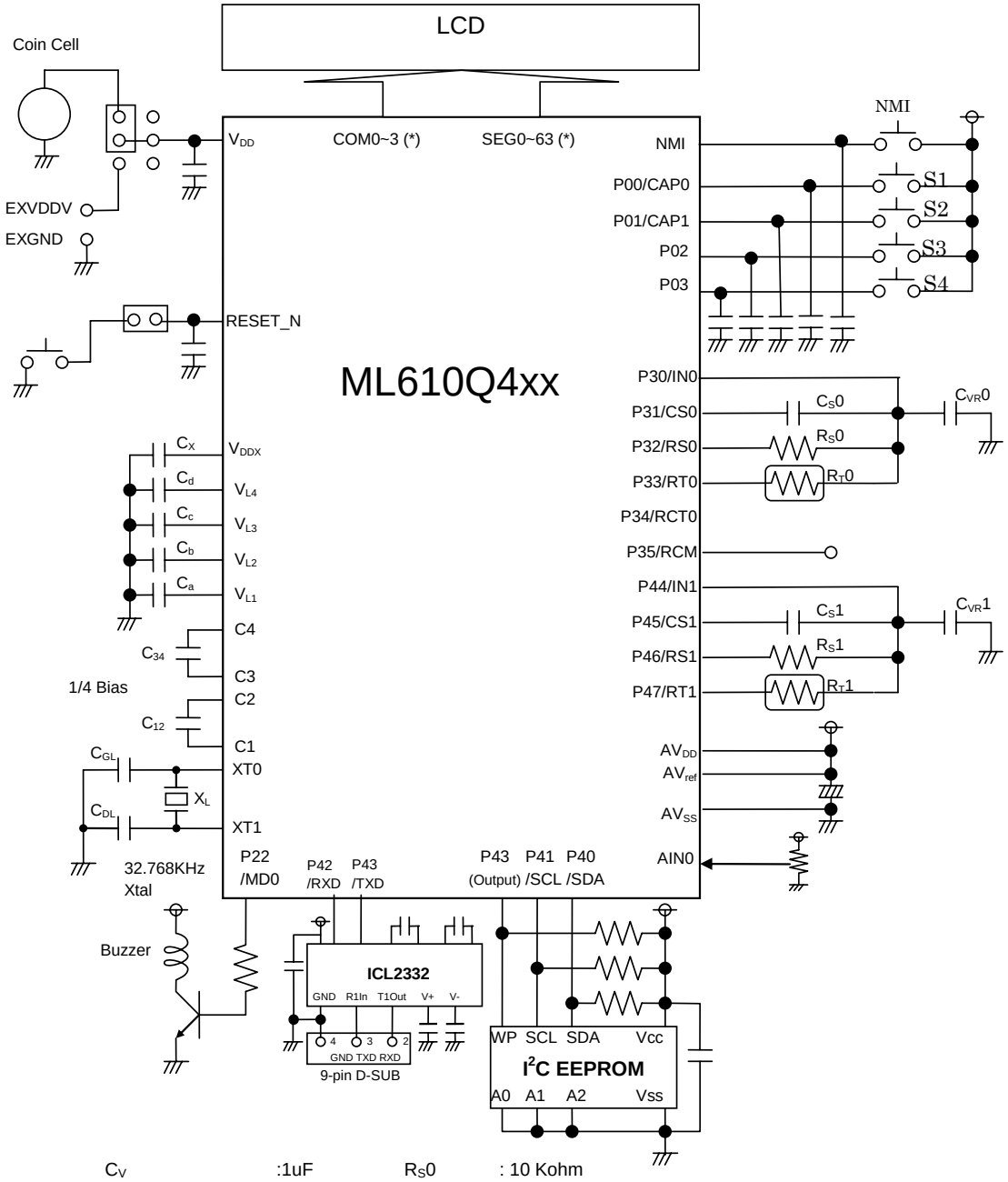
□The temperature is over 25 degrees centigrade. Therefore calculate the humidity at 40 degrees using the 45 degrees centigrade table
RH45 = ((4000 - 3059) × 2795 + 49250937) >> 20 = 49

□Calculate an objective humidity (RH) from RH25 and RH45.
RH＝RH25 -（（RH25 - RH45） / 20）×（T - 25）
=57 -（57 - 49） / 20× (40 - 25)
=57 - 6
=51(%)

2.4. Flowchart of humidity calculation



2.5. Typical Peripheral Circuit Diagram



C_V	:1uF	R_S0	: 10 Kohm
C_{L0}	:1uF	C_S0	: 560 pF
C_{L1}	:0.1uF	$C_{VR}0$	: 820 pF
C_1	:1uF	R_T0	: 103AT (Semitec) thermister
C_X	:0.1uF		
Ca,Cb,Cc,Cd	:1uF	R_S1	: 150 Kohm
C_{12},C_{34}	:1uF	C_S1	: 680 pF
C_{GL}	: No (0 pF)	$C_{VR}1$	: 820 pF
C_{DL}	: No (0 pF)	R_T1	: C10-M53R (Shinyei) humidity sensor

Fig2-5 Peripheral Circuit Diagram

(*) The number of COM/SEG pin that can be connected to LCD panel depends on the type of the LCD driver built into the MCU. Please see the chapter “LCD Driver” of the User’s Manual for your target MCU.

For more detail about the peripheral curcuit, please see the “ML610Q400 Series Demo Kit Hardware User’s Manual”.

2.6. How to prepare the Humidity ratio - Humidity conversion table

2.6.1. Selection of the reference resistor

This humidity calculation module calculates the humidity value by using the frequency count value from RC-ADC oscillation of the humidity sensor and the reference resistor. Therfore it is necessary to estimate the frequency count value of the humidity sensor, in advance.
If the frequency count value of the humidity sensor and the reference resistor is the same, we can regard that the humidity sensor and the reference resistor have the same impedance. It means that the frequency count value of the humidity sensor can be estimated as the ratio against the count value of the reference resister, from the humidity-resistance characteristics of the humidity sensor.

Example:
In the following case,
the reference resistor = 150 Kohm
the frequency count value of the humidity sensor = 2040
the frequency count value of the reference resistor = 1024
the ratio of frequency count (the humidity sensor / the reference resistor) is about 2. The impedance of the humidity sensor can be estimated to be about 300 Kohm.

* About the way of calculating the frequency count value from the resistance (impedance), refer to the chapter "RC Oscillation Type A/D Converter (RC-ADC)" of the User's Manual for your target MCU.

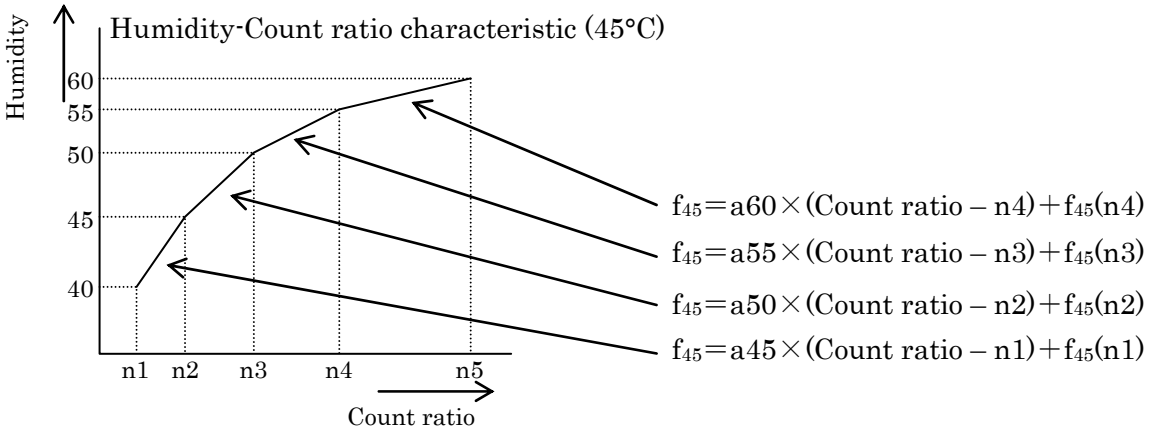
For the sample program, the resister of 150 Kohm is selected as the reference resistor so that the ratio of frequency count is 1 on the condition that temparature is 25 degrees centigrade and humidity is 45%rh.

2.6.2. Conversion from the Humidity-Resictance chracteristic to the Humidity-Count ratio charateristic

To estimate the RC-ADC frequency count value and calculate the humidity at each temparature (25, 45 and 5 degrees centigrade), follow the procedure below.

1. Calculate the RC-ADC frequency count value of the reference resistor (150 Kohm), from the Humidity-Resistance characteristic at 25 degrees centigrade.
2. Similarly, calculates the RC-ADC frequency count value of other impedances. Then, calculate the ratio (A) against the count value that was calculated in the above procedure 1, and make the approximation formula (f_{25}).
3. Extract the impedance of the humidity sensor from the Humidity-Resistance characteristic at 45 degrees centigrade. Then, calculates the RC-ADC frequency count value and the ratio against the count value of the reference resistor for each impedance of the humidity sensor.
4. Make the the approximate formula (f_{45}) of the Humidity-Count ratio characteristic, from the result of the above procedure 3.
   Example:

%rh	Impedance at 45°C	Count ratio against the reference resistor
40	100	250
45	60	500
50	37	1000
55	24	2000
60	15	4000



5. Similarly, extract the impedance of the humidity sensor from the Humidity-Resistance characteristic at 5 degrees centigrade. Then, calculates the RC-ADC frequency count value and the ratio against the count value of the reference resistor for each impedance of the humidity sensor. From this result, make the the approximate formula (f_5) of the Humidity-Count ratio characteristic.

Note: If the RC-ADC frequency count value is not enough to calcurate the count ratio, it is necessary to consider adjusting the reference registor and the capacitor (Cs).

2.6.3. Making up into a table for humidity calculation

By the following procedure, calculate the slope and offset of the approximate formula of the Humidity-Count ratio characteristic for 25, 45and 5 degrees centigrade, and make up them into a table. The resistance at the condition that temparature is 25 degrees centigrade and humidity is 45%rh is selected as the reference register, and the count ratio against this reference registor is searched in the table. Therefore it is necessary to calculate the humidity for 45 and 5 degrees centigrade, that corresponds to each entry of the count ratio in the Humidity-Count ratio characteristic for 25 degrees centigrade.

1. From the approximate formula (f_{45}), calculate the humidity f45(n25), which corresponds to each entry of the count ratio in the Humidity-Count ratio characteristic for 25 degrees centigrade.

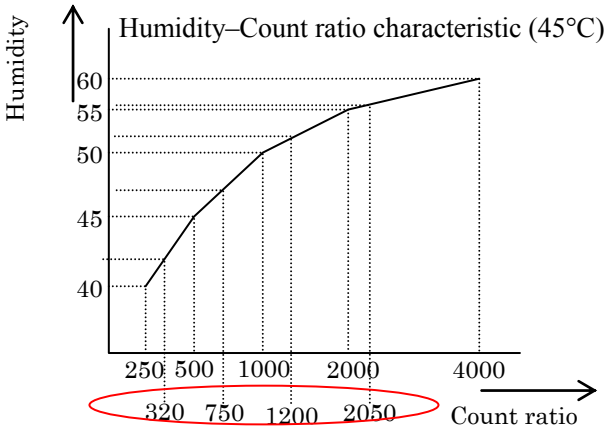
   Exampe:

%rh	Entry of count ratio in 25°C characteristic n_{25}
40	320
45	750
50	1200
55	2050
60	4010

Range of count ratio in 45℃ characteristic	Slope	Offset
250<= x < 500	$a_{45}40$	$b_{45}40$
500 <= x < 1000	$a_{45}45$	$b_{45}45$
1000 <= x < 2000	$a_{45}50$	$b_{45}50$
2000 <= x < 4000	$a_{45}55$	$b_{45}55$

When the count ratio is 320, the humidity at 45 °C is : $f45(320) = a_{45}40 * (320-250) + b_{45}40$
When the count ratio is 2050, the humidity at 45 °C is : $f45(2050) = a_{45}55 * (2050-2000) + b_{45}55$

2. By the above procedure, the humidity at 45 degrees centigrade, which corresponds to each entry of the count ratio in the Humidity-Count ratio characteristic for 25 degrees centigrade, is caluculated as follows.



3. Similarly, calculates the humidity at 5 degrees centigrade, which corresponds to each entry of the count ratio in the Humidity-Count ratio characteristic for 25 degrees centigrade.

4. Make up the following data into a table.
   - The count ratio at 25 degrees centigrade, that was calculated at the procedure 2 in the chapter 2.6.2.(A)
   - The slope in the Humidity-Count ratio characteristic at 25 degrees centigrade.
   - The offset in the Humidity-Count ratio characteristic at 25 degrees centigrade.
   - The slope in the Humidity-Count ratio characteristic at 45 degrees centigrade.
   - The offset in the Humidity-Count ratio characteristic at 45 degrees centigrade.
   - The slope in the Humidity-Count ratio characteristic at 5 degrees centigrade.
   - The offset in the Humidity-Count ratio characteristic at 5 degrees centigrade.

3. Celsius Fahrenheit conversion module

3.1. function overview

This module converts from Fahrenheit to Celsius.

Table3.1 API list

Function name	function
convertCtoF_asm	Convert from Celsius degrees centigrade to Fahrenheit degrees centigrade. $F = \frac{9}{5}C + 32$

3.2. Operation condition

This section describes operating conditions, valid range, restrictions of this module.

Calculation range :105.0~-50.0 degrees centigrade

[Note]

U8 has a powerful 'Decimal adjustment instruction'. And this instruction is so useful for this module. However, CCU8 compiler does not support this instruction. So, this module is made by assembler language.

By using' Decimal adjustment instruction' and shift operation, it is possible to process this conversion effectively

See the below description for more detail.

Operation overview

Transform the expression to process faster like the below:

①F=9/5C+32=1.8C+32 // Decompose 1.8C to C+8/10C

②1.8C=C+8C/10=C+((C+C)×2)×2/10 // 8 can transform to 2x2x2. Then it is possible to use shift operation instead of multiple operation.

③if C>=0 then
  F= (C+((C+C)×2)×2/10)+32
else
  F=32-(C+((C+C)×2)×2/10)
end

Revision History

Revision History

Edition	Isuue Date	Page		Contents
		Before	After	
1	June 26, 2009	-	-	First Edition
2	January 27, 2010	5	2	Description about the resistance mesurement method, which is used by the temperature calculation module, is corrected.