

# MM908E625 / MM908E626 - Factory Trimming and Calibration

## 1 Introduction

During final test of the MM908E625 / MM908E626, various parameters (such as, ICG trim value) are measured and stored into the device internal FLASH memory for internal and also for customer use. The purpose of these parameters is to enhance the accuracy of the MM908E625 / MM908E626 and reduce end of line calibration for the customer (for example, no ICG trimming necessary).

The following flash memory locations are reserved for this purpose and might have a value different from the “empty” (0xFF) state:

- 0xFD80:0xFDDF Trim and Calibration Values
- 0xFFFE:0xFFFF Reset Vector

In the event the application uses these parameters, one has to take care not to erase or override these values. If these parameters are not used, these flash locations can be erased and otherwise used.

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## 2 General Description

### 2.1 Example Source Codes

For the C-source code examples the Metrowerks CodeWarrior was used. The assembly language examples are done in a generic way and are not specific to one Assembler. All source codes are just one way of implementing the trimming, and might or might not fit the requirements of a specific application.

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### 2.2 FLASH Block Protection (page erase/mass erase)

The microcontroller core of the MM908E625 / MM908E626 is the MC68HC908EY16. The FLASH memory of this device has a built-in protection. This protection can protect the FLASH memory against erasing and overwriting. The amount of memory which is protected can be selected with the FLASH Block Protect Register (FBPR). By default, the last page (0xFFDC:0xFFFF) of the FLASH memory, containing the vector table, is always protected and can only be erased with Mass Erase. In the case that the trim values are used, the device needs special handling for FLASH programming, for example:

- the FLASH area containing the trimming data has to be read
- the device FLASH memory has to be erased (mass erase)
- the FLASH has to be programmed with the program and the trimming data has to be reprogrammed

## 2.3 Available Trimming Data - Overview

The following table shows the user available trim data in the MM908E625 / MM908E626.

**Table 1. Trim Data Memory Map <sup>(1)</sup>**

|   | HOT    | COLD   | ROOM   |
|---|--------|--------|--------|
| ICG Trim 307.2kHz, 1%                       | n.a.   | n.a.   | 0xFDC2 |
| H-Bridge LS Current Recopy, HB1, Ratio High | 0xFD83 | 0xFDA3 | 0xFDC3 |
| H-Bridge LS Current Recopy, HB2, Ratio High | 0xFD84 | 0xFDA4 | 0xFDC4 |
| H-Bridge LS Current Recopy, HB3, Ratio High | 0xFD85 | 0xFDA5 | 0xFDC5 |
| H-Bridge LS Current Recopy, HB4, Ratio High | 0xFD86 | 0xFDA6 | 0xFDC6 |
| H-Bridge LS Current Recopy, HB4, Ratio Low  | 0xFD87 | 0xFDA7 | 0xFDC7 |
| H-Bridge LS Current Recopy, HB4, Ratio Low  | 0xFD88 | 0xFDA8 | 0xFDC8 |
| H-Bridge LS Current Recopy, HB4, Ratio Low  | 0xFD89 | 0xFDA9 | 0xFDC9 |
| H-Bridge LS Current Recopy, HB4, Ratio Low  | 0xFD8A | 0xFDAA | 0xFDCA |
| VSUPRatio_TRIM                              | 0xFD8B | 0xFDAB | 0xFDCB |
| H-Bridge LS Current Limitation Value CL1    | 0xFD90 | n.a.   | 0xFDD0 |
| H-Bridge LS Current Limitation Value CL2    | 0xFD91 | n.a.   | 0xFDD1 |
| H-Bridge LS Current Limitation Value CL3    | 0xFD92 | n.a.   | 0xFDD2 |
| H-Bridge LS Current Limitation Value CL4    | 0xFD93 | n.a.   | 0xFDD3 |
| H-Bridge LS Current Limitation Value CL5    | 0xFD94 | n.a.   | 0xFDD4 |
| Temperature Sensor Trim Value               | 0xFD95 | 0xFDB5 | 0xFDD5 |

### Notes

1.Memory range for trim data 0xFD80..0xFDDF, all memory locations within that range not mentioned above should be ignored.

## 3 Functional Description

### 3.1 Internal Clock Generator (ICG) Trim Value

The internal clock generator (ICG) module is used to create a stable clock source for the microcontroller without using any external components.

With the [MC68HC908EY16](#) data sheet, the trimming information for the ICG is part of the Microcontroller specification. Refer to the “ICG Trim Value” chapter for details.

### 3.2 H-Bridge LS Current Recopy

To determine the Current Recopy Trim value, the Current Sense Amplification is disabled, all HB Low Sides are switched on, and Current Recopy is sequentially selected as analog input for the ADC from HB1 to HB4. For each HB pin, 150 mA is injected into the HB pin, and after a wait time of 1.0 ms, a conversion is triggered. The same sequence is executed after enabling Current Sense Amplification (RATIO).

The Current Recopy Ratio measurements on HBx pins are converted to trim values using the following formula:

$$CRRatio = ((Digital\ Code \times V_{REFH}) / 1023) / I_{LOAD}, \text{ where } V_{REFH} = 5.0\ V \text{ and } I_{LOAD} = 150\ mA$$

$$CRRatio\_TRIM = (ref\_value \times 128) / CRRatio \text{ where } ref\_value = 2, \text{ when } CSA = 0, \text{ and } 12 \text{ when } CSA = 1$$

The trim values (CRRatio\_TRIM) for all three temperatures are stored in the FLASH memory location documented in [Table 1](#).

### 3.3 VSUP Ratio

The following formula is applied to get the VSUPRatio value:

$$VSUPRatio = V_{SUP} / ((Digital\ Code \times V_{REFH}) / 1023) \text{ where } V_{REFH} = 5.0\ V \text{ and } V_{SUP} = 16\ V$$

Based on this result, the trim adjustment is calculated:

$$VSUPRatio\_TRIM = (ref\_value \times 128) / VSUPRatio \text{ where } ref\_value=5.1$$

The trim values (VSUPRatio\_TRIM) for all three temperatures are stored in the FLASH memory location documented in [Table 1](#).

### 3.4 H-Bridge LS Current Limitation Value

For each current limitation level, the values determined on all four low sides are averaged to determine the right trim adjustment through the following formulas:

- $CL1\_TRIM = (ref\_value \times 128) / AVERAGE\_CL1\_4HBs$ , where  $ref\_value = 55\ mA$
- $CL2\_TRIM = (ref\_value \times 128) / AVERAGE\_CL2\_4HBs$ , where  $ref\_value = 260\ mA$
- $CL3\_TRIM = (ref\_value \times 128) / AVERAGE\_CL3\_4HBs$ , where  $ref\_value = 370\ mA$
- $CL4\_TRIM = (ref\_value \times 128) / AVERAGE\_CL4\_4HBs$ , where  $ref\_value = 550\ mA$
- $CL5\_TRIM = (ref\_value \times 128) / AVERAGE\_CL5\_4HBs$ , where  $ref\_value = 740\ mA$

The trim value for the hot and room temperature test is stored in the FLASH memory location documented in [Table 1](#).

### 3.5 Internal Die Temperature Sensor - Offset Calibration Value

The internal die temperature sensor allows monitoring the analog die temperature. Due to the nature of the sensor, the linearity has little influence on process variations, but the offset of the sensor has a significant variance.

**Table 2. Internal Die Temperature Slope**

|                           |            |     |     |     |       |
|---------------------------|------------|-----|-----|-----|-------|
| Voltage/Temperature Slope | $S_{TTOV}$ | -   | 19  | -   | mV/°C |
| Output Voltage @ 25 °C    | $V_{T25}$  | 1.7 | 2.1 | 2.5 | V     |

As indicated in the datasheet, the output voltage at 25 °C can vary up to ±400 mV, which corresponds to an offset error of ±21 °C. The slope value is specified as typical only.

To compensate for this variation, the offset is measured during final test (3 temperatures) using the internal analog-to-digital converter, and stored into the FLASH memory. The conversion is performed as a 10-Bit AD conversion, the values are converted to 8-Bit accuracy before flashing. The values can be used by the application software to compensate the offset mentioned previously.

[Table 3](#) shows the location and content of the FLASH temperature trimming information stored in the MC68HC908EY16.

Table 3. Temperature Offset Trimming Flash Content<sup>(1)</sup>

| Flash Location | Register Content                      | Test Limits <sup>(2),(3)</sup> | Real Variation <sup>(2),(4)</sup> |
|----------------|---------------------------------------|--------------------------------|-----------------------------------|
| \$FD95         | Hot Temperature Offset ( $N_{T135}$ ) | 125 °C to 145 °C               | 133 °C to 138 °C                  |
| \$FDB5         | Cold Temperature Offset ( $N_{T40}$ ) | -43 °C to -32 °C               | -34 °C to -41 °C                  |
| \$FDD5         | Room Temperature Offset ( $N_{T25}$ ) | 16 °C to 35 °C                 | 26 °C to 31 °C                    |

## Notes

1. Stored as an 8-Bit ADC conversion result
2. Device Temperature during final test trimming,  $V_{SUP} = 16\text{ V}$
3. Maximum variation allowed during production
4. Three production lots with different testers

Offset Compensation Usage using the Room Temperature Offset ( $N_{T25}$ ):

The analog die temperature *ChipTemp* can be calculated with the following equation

$$\text{ChipTemp} = 25^{\circ}\text{C} + \frac{V - V_{T25}}{S_{TtoV}}$$

with the measured voltage of the analog-to-digital voltage  $V$ , the reference offset voltage at 25 °C  $V_{T25}$  and the temperature to the voltage slope (sensor voltage resolution)  $S_{TtoV}$  of the sensor. For the chip temperature offset  $V_{T25}$ , the stored calibration value can be used instead using the typical value from the datasheet.

The measured voltage  $V_{ADC}$  can be evaluated from the actual measured analog-to-digital converter value  $N_{ADC}$  and the analog-to-digital resolution  $R_{ADC}$  with:

$$V_{ADC} = N_{ADC} \cdot R_{ADC}$$

The analog-to-digital resolution  $R_{ADC}$  for an 8-bit (truncated) conversion is:

$$R_{ADC} = \frac{5\text{V}}{255} \approx 19,6\text{mV}$$

Substituting the voltage  $V$  by the analog-to-digital value  $N$  leads to the following expression.

$$\text{ChipTemp} = 25^{\circ}\text{C} + \frac{R_{ADC}}{S_{TtoV}} \cdot (N - N_{T25})$$

which is the basis for the calculations of the chip temperature by the embedded software. With analog to digital converter “temperature resolution”:

$$\frac{R_{ADC}}{S_{TtoV}} = \frac{\frac{5\text{V}}{255}}{19 \frac{\text{mV}}{^{\circ}\text{C}}} \approx 1,032^{\circ}\text{C}$$

## Functional Description

Therefore the chip temperature *chip\_temp* can be calculated as:

$$\text{ChipTemp} = 25^{\circ}\text{C} + 1,032^{\circ}\text{C} \cdot (\text{N} - \text{N}_{\text{T}25})$$

### **Method 1** - exact calculation using float datatype

#### *C language example*

```
#include<stdlib.h>

// -----
// -- DEFINES --
// -----
#define IOBYTE(address) *((volatile unsigned char*) (address))
#define IOWORD(address) *((volatile unsigned int*) (address))
#define N_T25          OBYTE(0xFDD5)           // temperature offset calibration value (25C)
#define S_TtoV        0.019                   // 19mV per celsius
#define R_ADC         (5.0/255)              // ADC resolution (8bit)
// -----
// -- MAIN --
// -----
void main(void) {

    unsigned char N;                          // measure adc value (8-bit truncated mode)
    float ChipTemp;

    .....

    N = ADC_Value(0x0);                       // measure temp sensor voltage with adc
    ChipTemp = 25 + (R_ADC/S_TtoV) * (N - N_T25); // calculate chip temp

    .....

}
```

**Method 2 - approximation using integer datatype**

With an approximation for  $R_{ADC} / S_{TtoV25} = 1$  the chip temperature ChipTemp simplifies to

$$\text{ChipTemp} = 25^{\circ}\text{C} + (N - N_{T25})$$

The relative error through the approximation is  $\sim 3.2\%$  or  $0.032^{\circ}\text{C/bit}$ . With the reference at  $25^{\circ}\text{C}$ , the maximum absolute error for the range of  $-40^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$  is

- $2.08^{\circ}\text{C}$  at  $-40^{\circ}\text{C}$  and
- $-3.2^{\circ}\text{C}$  at  $+125^{\circ}\text{C}$

As this is a known static error (systematic error), it also could be compensated by the software.

**C language example**

```
#include<stdlib.h>

// -----
// -- DEFINES --
// -----
#define IOBYTE(address) *((volatile unsigned char*) (address))
#define IOWORD(address) *((volatile unsigned int*) (address))

#define N_T25      IOBYTE(0xFDD5)           // temperature offset calibration value (25 °C)

// -----
// -- MAIN --
// -----
void main(void) {

    unsigned char N;           // measure adc value (8-bit truncated mode)
    int ChipTemp;

    .....

    N = ADC_Value(xxx);       // measure temp sensor voltage with adc
    ChipTemp = 25 + (N - N_T25); // calculate chip temp

    .....

}
```

**Comparison of the two methods**

[Table 4.](#) give a comparison between the two methods. It indicates the ROM, RAM/Stack size necessary just for the calculation (only the code line with the formula is considered), and compares the execution time for the calculation operation.

**Table 4. Performance Data**

|                                       | Method 1 - "Float"  | Method 2 - "Integer" |
|---------------------------------------|---------------------|----------------------|
| ROM size                              | 1161                | 30                   |
| RAM (ChipTemp) / Stack usage          | 4 / 44              | 2 / 3                |
| Cycles for calculation                | 4289                | 13                   |
| Execution time @5.0 MHz bus frequency | 857.8 $\mu\text{s}$ | 2.6 $\mu\text{s}$    |

The performance requirements for the Method 1 are significantly higher, for example, the execution time of method 1 is more than 300 times longer, the ROM memory is 38 times higher, and the RAM memory is 9 times higher.

### NOTE

The example given is using only one temperature point for calibration. Additional accuracy can be reached, including all three available points to calculate the device specific slope. It is recommended to calculate two slope factors for (-40...25 °C and 25 °...135 °C) based on the given trim values.

## 4 Comment / Summary

Based on the calibration method and the trim values used, a significant increase of accuracy of the MM908E625 / MM908E626 can be realized.

## 5 References

1. [MC68HC908EY16](#)
2. [MM908E625 Data Sheet](#)
3. [MM908E626 Data Sheet](#)



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