AN5067
Application note

How to optimize STM32 MCUs internal RC oscillator accuracy

Introduction

STM32 microcontrollers have two internal RC oscillators, known as the HSI (high-speed internal) and LSI (low-speed internal) oscillators. The HSI oscillator has a typical frequency of 8 MHz or 16 MHz depending on the product. The LSI oscillator is a lower speed, low-power clock source.

These internal RC oscillators have the advantage of providing a clock source at low cost (by removing the external components). They also have a faster startup time. However, the actual internal oscillator frequency is dependent on many factors that affect the final accuracy of the module once assembled on a PC board, including handling and shock, re-flow temperature profile, maximum temperature, and number of re-flows.

This application note describes how the expected accuracy of the STM32 microcontroller internal oscillators varies when mounted on a board, at room temperature and with temperature variation.

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1 General information

This document applies to Arm®-based devices.

2 Expected internal oscillator accuracy

2.1 Internal oscillator datasheet specifications

The product datasheet provides separate accuracy specifications for room temperature, at a fixed V_{DD} = 3 V, over V_{DDA} supply voltage variation, and over the rated temperature range.

The *Table 1* shows a portion of the STM32L052x6/STM32L052x8 datasheet extracted to show the overall conditions and the individual accuracy specifications.

Table 1. 16 MHz HSI16 oscillator characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
f_{HSI16}	Frequency	V_{DD} = 3.0 V	-	16	-	MHz
TRIM(1)(2)	HSI16 user-trimmed resolution	Trimming code is not a multiple of 16	-	±0.4	0.7	%
		Trimming code is a multiple of 16	-	-	±1.5	%
ACC_{HSI16} (2)	Accuracy of the factory-calibrated HSI16 oscillator	V_{DDA} = 3.0 V, T_A = 25 °C	-1(3)	-	1(3)	%
		V_{DDA} = 3.0 V, T_A = 0 to 55 °C	-1.5	-	1.5	%
		V_{DDA} = 3.0 V, T_A = -10 to 70 °C	-2	-	2	%
		V_{DDA} = 3.0 V, T_A = -10 to 85 °C	-2.5	-	2	%
		V_{DDA} = 3.0 V, T_A = -10 to 105 °C	-4	-	2	%
		V_{DDA} = 1.65 V to 3.6 V T_A = − 40 to 125 °C	-5.45	-	3.25	%
$t_{SU(HSI16)}$(2)	HSI16 oscillator startup time	-	-	3.7	6	µs
$I_{DD(HSI16)}$(2)	HSI16 oscillator power consumption	-	-	100	140	µA

1. The trimming step differs depending on the trimming code. It is usually negative on the codes which are multiples of 16 (0x00, 0x10, 0x20, 0x30...0xE0).
2. Guaranteed by characterization results.
3. Guaranteed by test in production.

- “Accuracy of the factory-calibrated HSI16 oscillator” refers to the maximum variation from a perfect 0% error with the device at an ambient temperature TA = 25°C and V_{DDA}= 3.0 V. Oscillator stability in this case refers to the average frequency measured over a period of time. The ±1% is the maximum guaranteed for a packaged device as it is shipped to the customer.

- “Oscillator Stability vs Temperature” is the maximum error measured when varying TA and keeping V_{DDA} constant. The reference is VDDA = 3 V and TA = 25°C.
- “Oscillator Stability vs Voltage” is the maximum deviation, going from -40°C to 125°C, from a perfect 0% error as the V_{DDA} voltage is varied from 1.65 V to 3.6 V.

2.2 Internal oscillator drift before and after re-flow

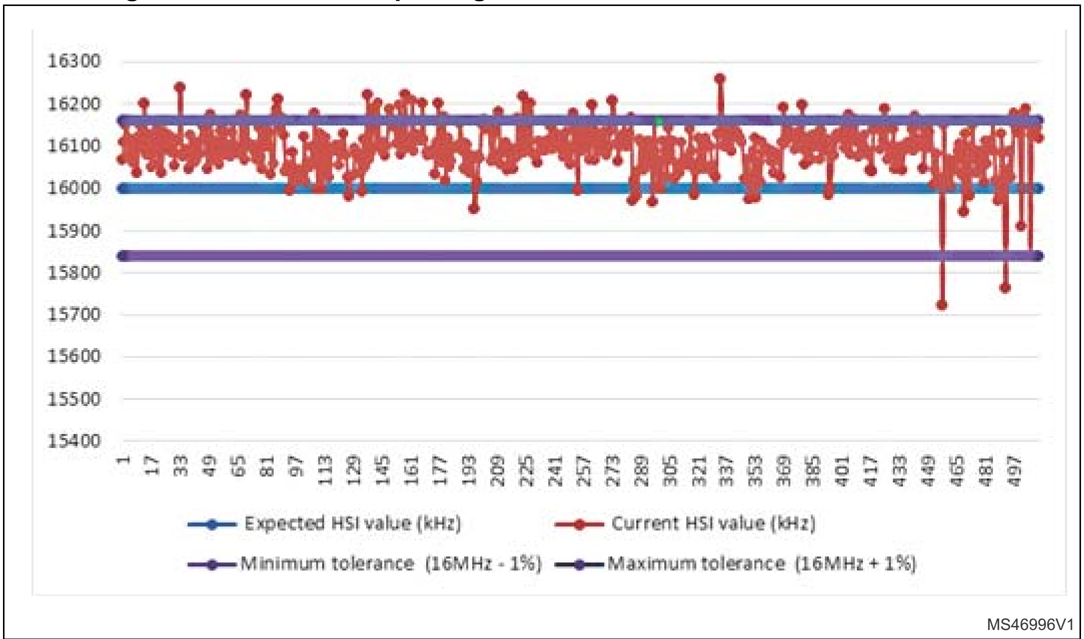
The High Speed Internal Oscillator (HSI) in all STM32 products shipped from the factory are calibrated to a typical accuracy value of ±1%. For example for products having HSI = 16 MHz, the HSI16 can be between 15840 kHz and 16160 kHz

Figure 1 shows results of measuring the HSI16 on 500 MCUs (STM32F767) after soldering them on a Nucleo-144 boards.

Blue line represent the expected HSI16 value in KHz (16000), purple lines represent the minimum and maximum HSI16 that can be tolerated (± 1%)

Notice that after soldering the MCU, a drift on the internal oscillator has occurred. This is due to the thermal and mechanical effects.

Figure 1. HSI drift after placing the STM32F767ZI on Nucleo-144 board



The main point of *Figure 1* is that, after soldering the device on a board, the accuracy specified in product datasheet have additional errors. Due to the variability of the re-flow process and customer application boards, there cannot be a maximum stated error. The best insurance of getting the finest accuracy is to minimize the pick and place time and temperature of the assembly re-flow process.

2.3 Internal oscillator drift and its impact

The deviation that may occur due to assembly re-flow process, could have an impact on the communication channels used by the internal bootloader.

In particular when using USB, the HSI is used to determine the frequency of the used external crystal. If the drift on the internal clock is too high, the frequency of the external clock is detected wrongly and the USB not work correctly. If the USB is used to upgrade the application firmware using bootloader (DFU) a 4 MHz external clock is recommended.

3 Environment Effects

3.1 Thermal effects

Typical surface mount production assembly flows include at least one infrared re-flow pass for soldering components to pads on the board. Heating profiles for re-flow cycles have peak temperatures of up to 260 °C for 10 to 30 seconds, which is high enough to slightly change the characteristics of the internal oscillator in the device. After cooling, the typical final effect on the device is a slightly lower oscillator frequency (sometimes but not often higher frequency). Therefore, the STM32 after re-flow assembly, have a different accuracy range than that specified on the datasheet as shipped from the factory.

The user must take this accuracy change into account when considering the final system accuracy for the assembled STM32 device on their boards. Also, every effort needs to be made to minimize the peak re-flow temperature and peak time as well as the number of re-flow cycles. Thus, reducing the frequency change after re-flow. For example, a re-flow process at +260°C peak temperature can add 2.5% error and the STM32 still be within the expected range

3.2 Mechanical effects

Usually at the end of the pick and place process, a PCB panel needs to have the single PCB separated from each other with a cutting tool or router.

Possible sources of the internal oscillator offset include mechanical shock or mechanical stress caused by a glue or PCB under fill.

Failure to observe proper precautions handling the device, before or after, assembly can result in higher than expected oscillator frequency error.

4 Environment effect compensation

The operating temperature and the environment effects have an impact on the accuracy of the internal oscillators.

To compensate the influence of these effects on internal oscillators' accuracy, the STM32 microcontrollers have built-in features to allow customers to calibrate and measure oscillator frequencies.

4.1 HSI calibration registers

This section describes in detail registers involved in the internal clock trimming.

4.1.1 HSI16 clock trimming

The HSITRIM register has five valid bits HSITRIM[4:0], which allows total 32 trim settings. Default is 16. When increasing the trim register value, the clock frequency increases accordingly.

4.1.2 HSI16 clock calibration

These bits are initialized at startup with the factory-programmed HSI16 calibration trim value. When HSITRIM is written, HSICAL is updated with the sum of HSITRIM and the factory trim value.

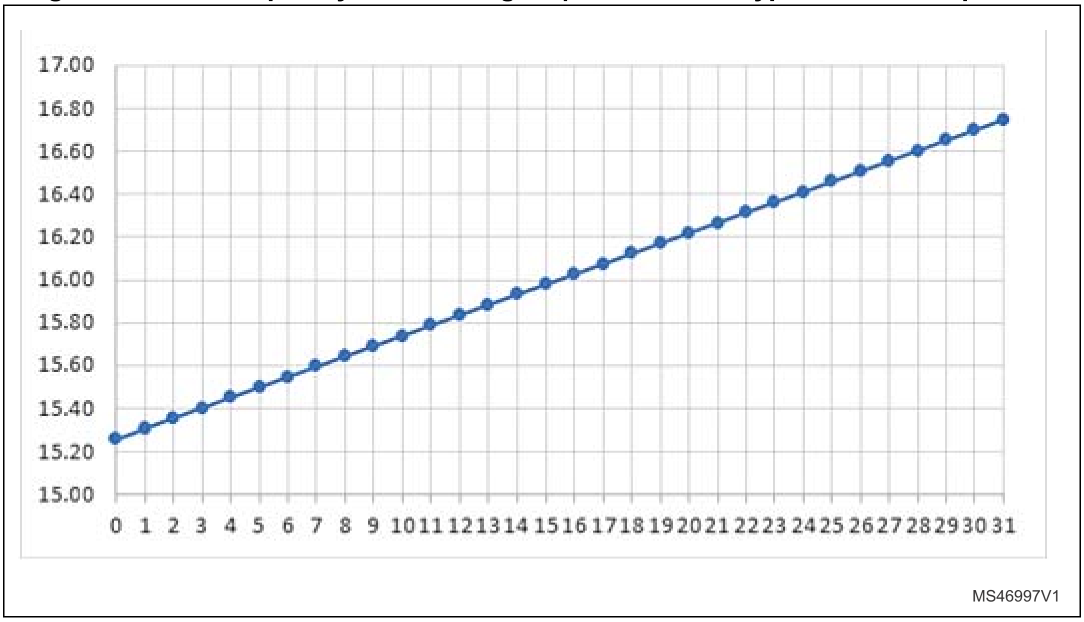
4.2 HSI calibration steps

The HSI oscillator can be trimmed by ±4.5% by writing the 5-bit value to the HSITRIM register. This trim value is set to 16 after any reset. Increasing this value by 0x01, increase the period of the oscillator by approximately 0.3% on STM32 products.

The trim value is not perfectly linear versus the HSI16 clock frequency, this is due to process variation, parasitic effect.

Figure 2 and *Figure 3* shows the HSI16 frequency versus trim values of a typical STM32F4 part and STM32L4 respectively.

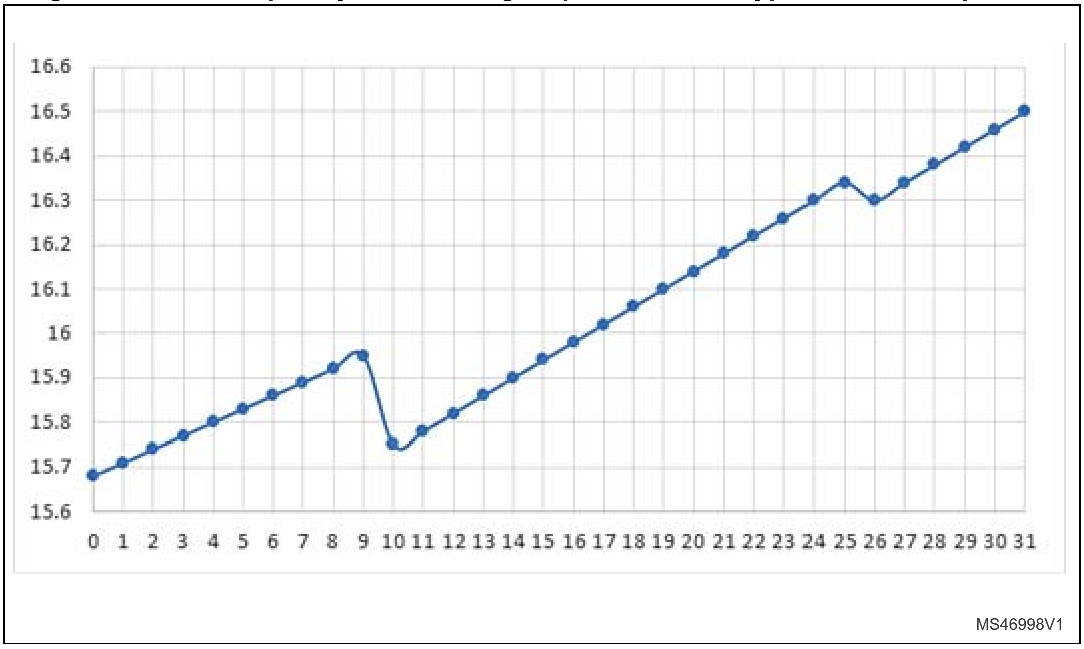
Figure 2. HSI16 frequency VS trimming steps values of a typical STM32F4 product



The HSI oscillator is fine-tuned in typical steps of 0.3% (around 48 kHz) and maximum steps of 1% (around 160 kHz).

- Writing a trimming value, in the range of 17 to 31, increases the HSI frequency.
- Writing a trimming value, in the range of 0 to 15, decreases the HSI frequency.
- Writing a trimming value, equal to 16, causes the HSI frequency to keep its default value.

Figure 3. HSI16 frequency VS trimming steps values of a typical STM32L4 product



An increase/decrease in this trimming value causes an increase/decrease in HSI frequency.

The HSI16 oscillator is fine-tuned in typical steps of 0.3% (around 48 kHz) and maximum steps of 0.5% (around 80KHz).

- Writing a trimming value in the range of 17 to 31 increases the HSI frequency.
- Writing a trimming value in the range of 0 to 15 decreases the HSI frequency.
- Writing a trimming value equal to 16 causes the HSI frequency to keep its default value.

The HSI oscillator frequency increases with calibration value (calibration value = default HSICAL[7:0] + HSITRIM[4:0]), except for products which have negative steps (like the STM32L4 products).

For these products there is a negative step when the calibration value is multiple of 16. The negative step can reach three times the positive step.

So user must take into account the negative steps during the calibration process. Refer to product datasheet for more information about the trimming steps.

For more details about internal oscillator calibration methods refer to below applications notes:

 – AN3300: How to calibrate an STM32L1xx internal RC oscillator,
 – AN4067: Calibrating STM32F0x1, STM32F0x2 and STM32F0x8 lines internal RC oscillators.
 – AN2868: STM32F10xxx internal RC oscillator (HSI) calibration.

5 Conclusion

The internal oscillator is a module that is present in all STM32 MCUs. The main advantage of this clock source is that it requires no external components and saves valuable pins on low pin count devices, which makes it very cost effective.

Even if internal oscillators are factory-calibrated, user must calibrate them in the operating environment, when a high-accuracy clock is required in the application.

This application note provides details about factors that affect the final accuracy of the module once assembled on a final board and explains the calibration principles.

6 Revision history

Table 2. Document revision history

Date	Revision	Changes
01-Mar-2018	1	Initial release.