AN2867
Application note

Guidelines for oscillator design on STM8AF/AL/S and STM32 MCUs/MPUs

Introduction

Many designers know oscillators based on Pierce-Gate topology (Pierce oscillators), but not all of them really understand how they operate, and only a few master their design. In practice, limited attention is paid to the oscillator design, until it is found that it does not operate properly (usually when the final product is already in production). A crystal not working as intended results in project delays, if not overall failure.

The oscillator must get the proper amount of attention during the design phase, well before moving to manufacturing, to avoid the nightmare scenario of products failing in application.

This document introduces the Pierce oscillator basics, and provides guidelines for its design. It also shows how to determine the external components, and provides guidelines for correct PCB design and for selecting crystals and external components.

To speed up the application development, the recommended crystals (HSE and LSE) for the products listed in *Table 1* are detailed in *Section 5: Recommended resonators for STM32 MCUs/MPUs* and *Section 6: Recommended crystals for STM8AF/AL/S MCUs*.

Table 1. Applicable products

Type	Product categories
Microcontrollers	STM8S series, STM8AF series and STM8AL series
	STM32 32-bit Arm® Cortex® MCUs
	STM32 Wireless MCUs
	STM32 Ultra Low Power MCUs
	STM32 High Performance MCUs
Microprocessors	STM32 Arm® Cortex® MPUs

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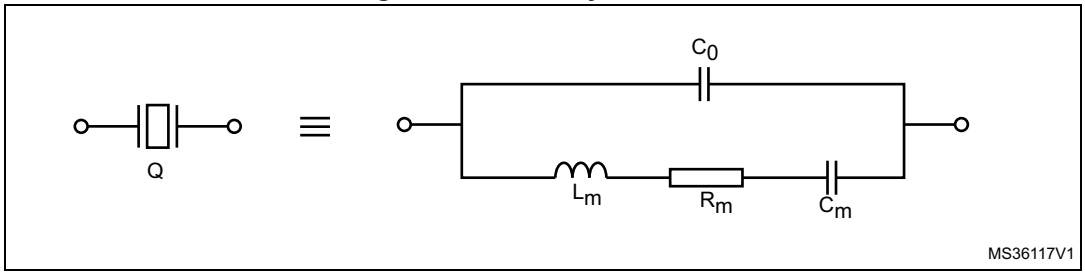
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1 Quartz crystal properties and model

A quartz crystal is a piezoelectric device converting electric energy into mechanical energy, and vice versa. The transformation occurs at the resonant frequency. The quartz crystal can be modeled as shown in *Figure 1*.

Figure 1. Quartz crystal model



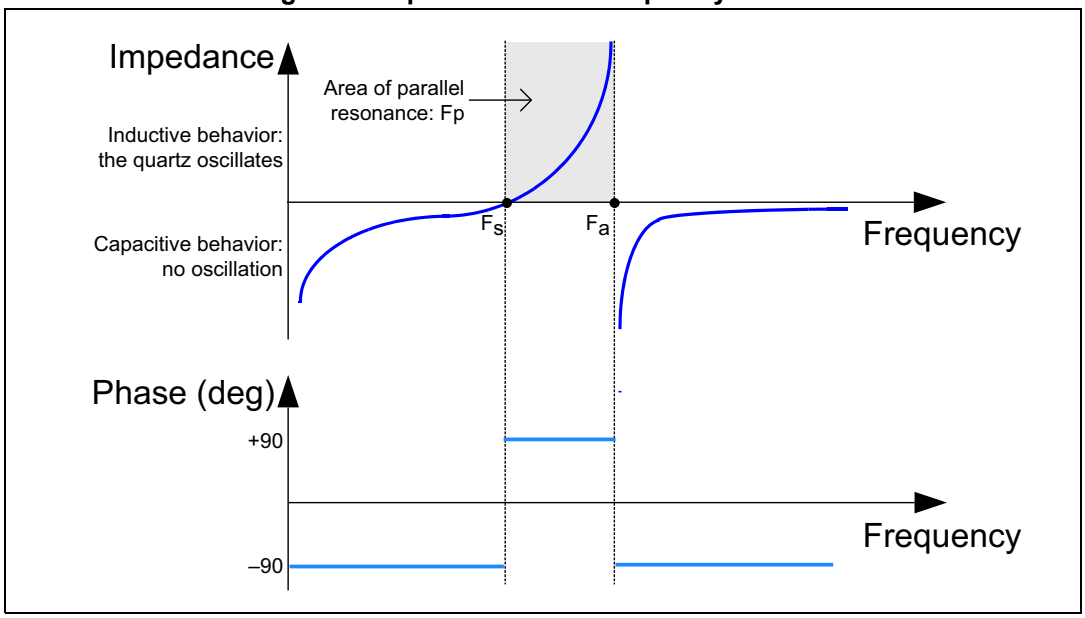
- C_0 represents the shunt capacitance resulting from the capacitor formed by the electrodes
- L_m (motional inductance) represents the vibrating mass of the crystal
- C_m (motional capacitance) represents the elasticity of the crystal
- R_m (motional resistance) represents the circuit losses

The impedance of the crystal (assuming that R_m is negligible) is

$$Z = \frac{j}{w} \times \frac{w^2 \times L_m \times C_m - 1}{(C_0 + C_m) - w^2 \times L_m \times C_m \times C_0} \quad (1)$$

Figure 2 shows the impedance in the frequency domain.

Figure 2. Impedance in the frequency domain



F_s is the series resonant frequency when Z = 0. Its expression can be deduced from equation *(1)* as follows:

$$F_s = \frac{1}{2\pi\sqrt{L_m C_m}} \quad (2)$$

F_a is the antiresonant frequency when Z tends to infinity. Using equation *(1)*, it is expressed as follows:

$$F_a = F_s\sqrt{1 + \frac{C_m}{C_0}} \quad (3)$$

The region delimited by F_s and F_a (shaded area in *Figure 2*) is the area of parallel resonance. In this region, the crystal operates in parallel resonance and behaves as an inductance that adds an additional 180° phase to the loop. Its frequency F_p (or F_L: load frequency) has the following expression:

$$F_p = F_s\left(1 + \frac{C_m}{2(C_0 + C_L)}\right) \quad (4)$$

According to this equation, the oscillation frequency of the crystal can be tuned by varying the load capacitance C_L. This is why, in their datasheets, crystal manufacturers indicate the exact C_L required to make the crystal oscillate at the nominal frequency.

Table 2 gives an example of equivalent crystal circuit component values for an 8 MHz nominal frequency.

Table 2. Example of equivalent circuit parameters

Equivalent component	Value
R_m	8 Ω
L_m	14.7 mH
C_m	0.027 pF
C_0	5.57 pF

Using equations *(2)*, *(3)*, and *(4)*, it is possible to calculate F_s, F_a, and F_p of this crystal:

- F_s = 7988768 Hz
- F_a = 8008102 Hz

If the load capacitance C_L is equal to 10 pF, the crystal oscillates at F_p = 7995695 Hz.

To have an oscillation frequency of exactly 8 MHz, C_L must be 4.02 pF.

2 Oscillator theory

Oscillators are among the backbone components of modern digital ICs. They can be classified into different subfamilies, depending upon their topology and operating principles. For each subfamily there is a mathematical model that can be used to study the oscillator behavior, and theoretically determine its performance.

This section deals only with harmonic oscillators (relaxation oscillators are out of the scope of this document), with particular focus (see *Section 3*) on Pierce oscillators. This is because all the oscillators requiring external passive components (resonator, load capacitors, etc.) covered by this document are of the previously mentioned type and topology.

The harmonic oscillator family can be divided into two main subfamilies:

- negative-resistance oscillators
- positive-feedback oscillators.

These two subfamilies of oscillators are similar for what concerns the output waveform. They deliver an oscillating waveform at the desired frequency. This waveform is typically composed of a fundamental sine wave of the desired frequency, plus a sum of overtone harmonics (at frequencies multiple of the fundamental one), due to the nonlinearity of components of the oscillation loop.

The two subfamilies differ in their operating principles. A specific mathematical model describes and analyzes each of them.

Positive-feedback oscillators are usually modeled using the Barkhausen model, where an oscillator must fulfill the Barkhausen criterion to maintain a stable oscillation at the desired frequency.

The Barkhausen model is not fully adequate to describe negative-resistance oscillators: the most suitable approach is to use the negative-resistance model described in *[1]*.

STM32 microcontrollers and microprocessors (based on Arm®(a) cores) feature low-speed external (LSE) and high-speed external (HSE) oscillators designed according to the negative-resistance principle, hence this section focuses on the presentation of this model.

2.1 Negative resistance

Theoretically speaking, a negative resistance is a dipole that absorbs heat and converting it in electrical current, proportional to the applied voltage, but flowing in the opposite direction (the opposite mechanism of an electrical resistance). In the real world, such a dipole does not exist.

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The term negative resistance is a misnomer of negative transresistance, defined as the ratio between a given voltage variation (ΔV) and the induced current variation (ΔI). Unlike the resistance, always positive, the transresistance (also known as differential resistance) can be either positive or negative. *Figure 3* shows the current-voltage curve for a dipole with a negative transresistance region. It is obvious that the V/I ratio is always positive, this is not the case for the ΔV/ΔI ratio.

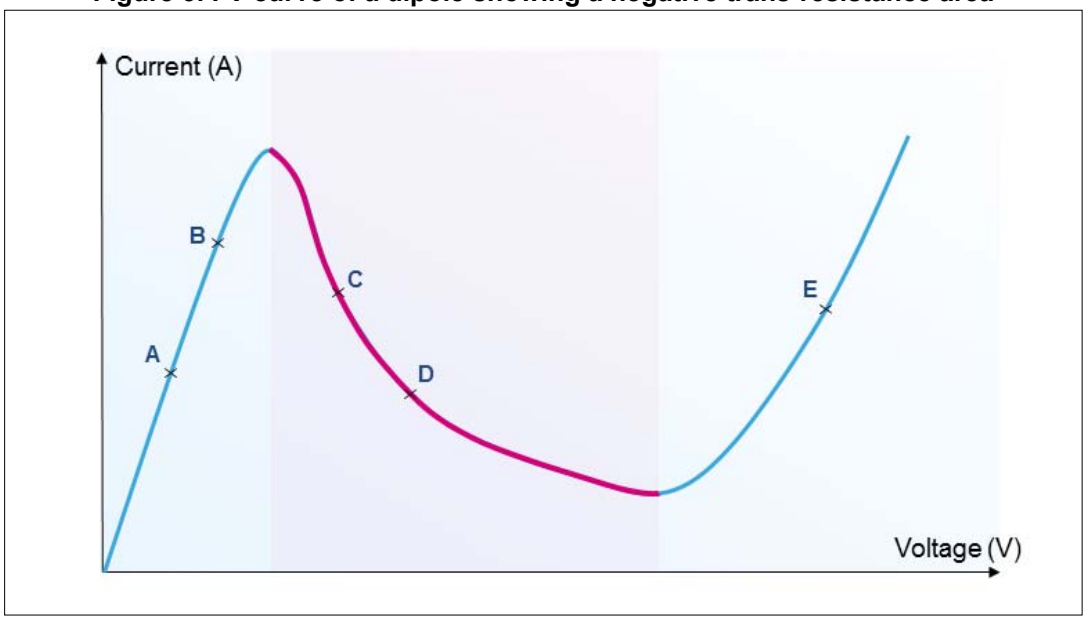
The portion of the I-V curve in purple shows a negative transresistance:

$$\frac{\Delta V}{\Delta I} = \frac{V(D) - V(C)}{I(D) - I(C)} < 0$$

The portions in blue feature a positive transresistance:

$$\frac{\Delta V}{\Delta I} = \frac{V(B) - V(A)}{I(B) - I(A)} > 0$$

Figure 3. I-V curve of a dipole showing a negative trans-resistance area



2.2 Transconductance

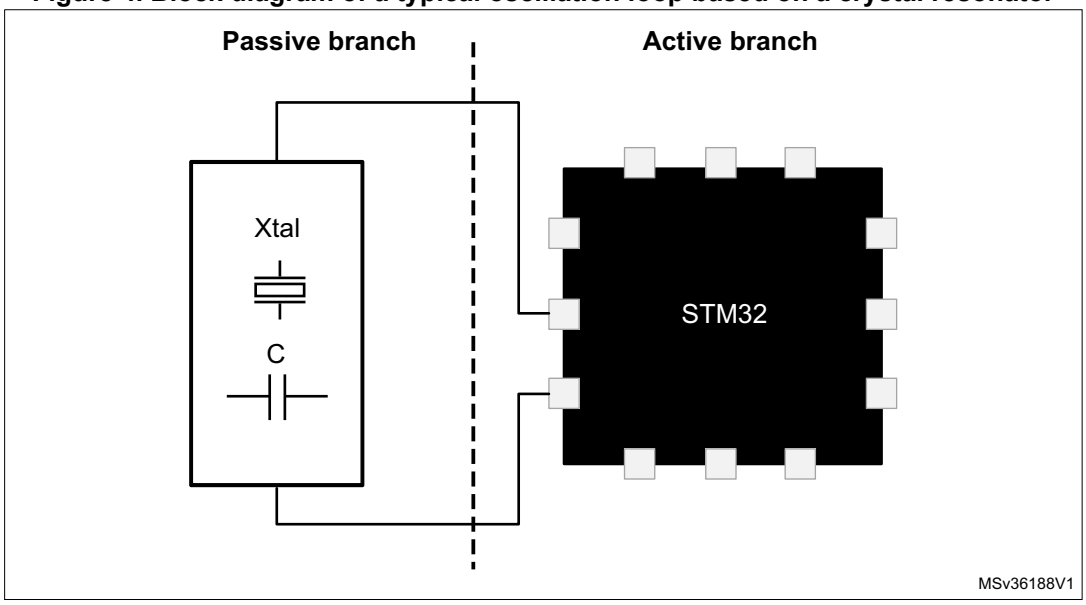
Similarly to the conductance, defined as the inverse of the resistance, the transconductance is defined as the inverse of the transresistance. Transconductance can also be defined as the differential conductance, expressed as ΔI / ΔV.

2.3 Negative-resistance oscillator principles

An oscillation loop is made of two branches (see *Figure 4*):

- The active branch, composed by the oscillator itself, provides the energy to make the oscillation start and build up until it reaches a stable phase. When a stable oscillation is reached, this branch provides the energy to compensate for the losses of the passive branch.
- The passive branch is mainly composed by the resonator, the two load capacitors and all the parasitic capacitances.

Figure 4. Block diagram of a typical oscillation loop based on a crystal resonator



According to the small signals theory, when the active branch (oscillator part) is correctly biased, to maintain a stable oscillation around the oscillator biasing voltage the latter must have its transconductance equal to the passive branch conductance.

However, at startup, the oscillator transconductance must be higher than (multiple of) the conductance of the passive part of the oscillation loop, to maximize the possibility to build up the oscillation from the inherent noise of the loop. An excessive oscillator transconductance compared to the oscillation loop passive branch conductance can saturate the oscillation loop, and cause a startup failure.

To ensure the successful oscillator start, and to maintain stable oscillation, the ratio between the negative resistance of the loop and the crystal maximal equivalent series resistance (ESR) is specified for STM32 and STM8 products. It is recommended to have a ratio higher than 5 for the HSE oscillators, and higher than 3 for the LSE oscillators.

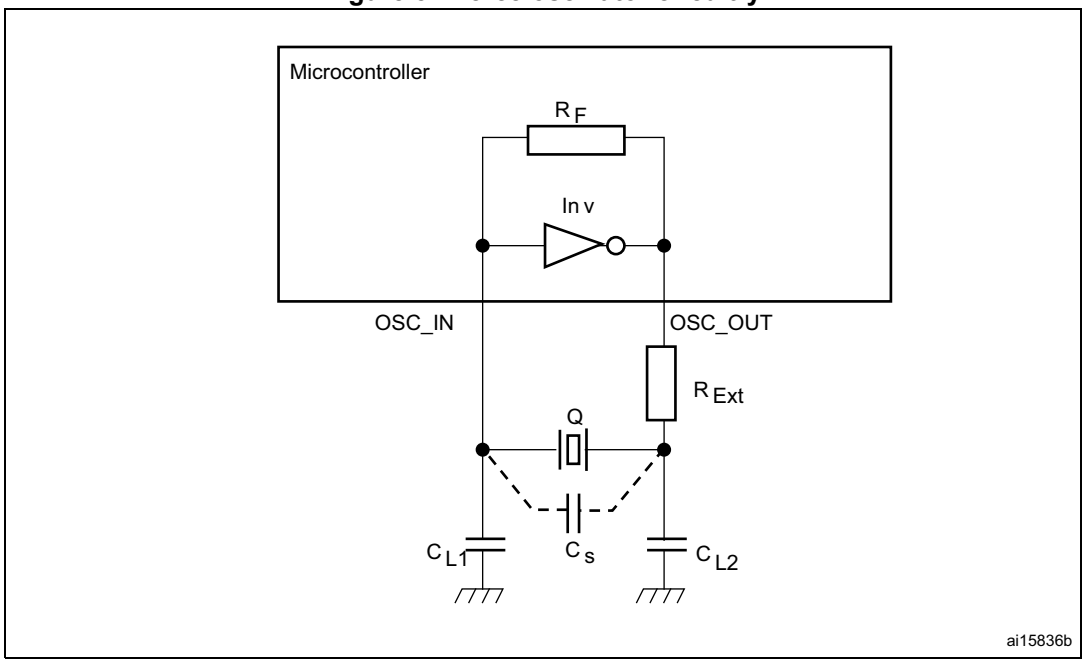
3 Pierce oscillator design

This section describes the different parameters, and how to determine their values to be compliant with the Pierce oscillator design.

3.1 Introduction to Pierce oscillators

Pierce oscillators are variants of Colpitts oscillators, widely used with crystal resonators. A Pierce oscillator (see *Figure 5*) requires a reduced set of external components, this results in a lower final design cost. In addition, the Pierce oscillator is known for its stable oscillation frequency when paired with a crystal resonator, in particular a quartz-crystal resonator.

Figure 5. Pierce oscillator circuitry



- Inv: the internal inverter that works as an amplifier
- Q: crystal quartz or a ceramic resonator
- R_F: internal feedback resistor
- R_{Ext}: external resistor to limit the inverter output current
- C_{L1} and C_{L2}: are the two external load capacitances
- C_s: stray capacitance, sum of the device pin (OSC_IN and OSC_OUT) and the PCB (a parasitic) capacitances.

3.2 Feedback resistor

In most MCUs/MPUs manufactured by ST, R_F is embedded in the oscillator circuitry. Its role is to make the inverter act as an amplifier. The feedback resistor is connected between V_{in} and V_{out} to bias the amplifier at $V_{out} = V_{in}$, and force it to operate in the linear region (shaded

area in *Figure 6*). The noise (for example, the thermal noise of the crystal) is amplified within the range of serial to parallel frequency (F_a, F_p), thus starting the oscillation.

Figure 6. Inverter transfer function

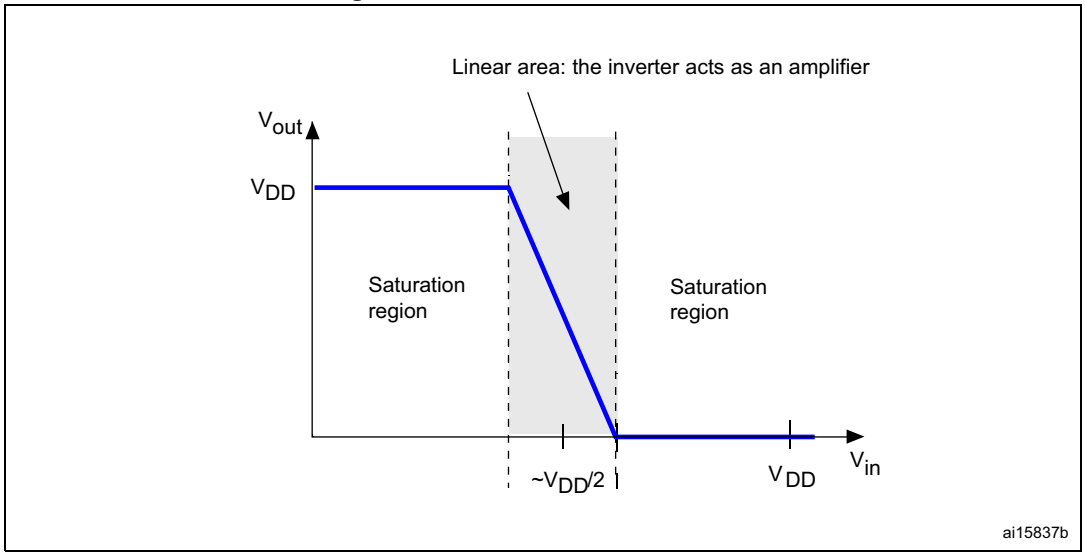


Table 3 provides typical values of R_F.

Table 3. Typical feedback resistor values for given frequencies

Frequency	Feedback resistor range
32.768 kHz	10 to 25 MΩ
1 MHz	5 to 10 MΩ
10 MHz	1 to 5 MΩ
20 MHz	470 kΩ to 5 MΩ

3.3 Load capacitance

The load capacitance is the terminal capacitance of the circuit connected to the crystal oscillator. This value is determined by the external capacitors C_{L1} and C_{L2}, and the stray capacitance of the printed circuit board and connections (C_s). The C_L value is specified by the crystal manufacturer. For the frequency to be accurate, the oscillator circuit must show the same load capacitance to the crystal as the one the crystal was adjusted for. Frequency stability requires that the load capacitance be constant. The external capacitors C_{L1} and C_{L2} are used to tune the desired value of $C_{L,}$ to reach the value specified by the crystal manufacturer.

The following equation gives the expression of C_L:

$$C_L = \frac{C_{L1} \times C_{L2}}{C_{L1} + C_{L2}} + C_s$$

For example, with C_L = 15 pF and C_s = 5 pF ,

$$C_L - C_s = \frac{C_{L1} \times C_{L2}}{C_{L1} + C_{L2}} = 10 \text{ pF}$$

hence $C_{L1} = C_{L2}$ = 20 pF.

3.4 Oscillator transconductance

Theoretically, to make the oscillation start and reach a stable phase, the oscillator must provide sufficient gain to compensate for the loop losses and to provide the energy for the oscillation buildup. When the oscillation becomes stable, the power provided to the oscillator and the one it dissipates in the loop are equal.

Practically, because of tolerances on passive component values and their dependency upon environmental parameters (such as temperature), the ratio between oscillator gain and oscillation loop critical gain cannot just exceed 1. This would induce a too long oscillator startup time, and even prevent the oscillator from starting up.

This section describes the two approaches that can be used to check if an STM32 oscillator can be paired with a given resonator, to ensure that the oscillation is started and maintained under the specified conditions for both resonator and oscillator. The approach depends on how the oscillator parameters are specified in the device datasheet:

- If the oscillation loop maximum critical transconductance parameter ($G_{m_crit_max}$) is specified, ensure that it is greater than the oscillation loop critical crystal gain (g_{mcrit}, see the formula below). Note that the maximum critical crystal transconductance can be named either $G_{m_crit_max}$ or G_m, depending on the STM32 product documentation.
- If the oscillator transconductance parameter (g_m) is specified, make sure that the gain margin ratio ($gain_{margin}$) is bigger than 5.

The gain margin ratio is determined by the formula $gain_{margin} = g_m / g_{mcrit}$, where

- g_m is the oscillator transconductance specified in the STM32 datasheet. The HSE oscillator transconductance is in the range of a dozen of mA/V, while the LSE oscillator transconductance ranges from a few to a few dozens of µA/V, depending upon the product.
- g_{mcrit} is defined as the minimal transconductance required to maintain a stable oscillation when it is a part of the oscillation loop for which this parameter is relevant. g_{mcrit} is computed from oscillation loop passive components parameters.

Assuming $C_{L1} = C_{L2}$, and that the crystal sees the same C_L on its pads as the value given by the crystal manufacturer, g_{mcrit} is expressed as follows:

$$g_{mcrit} = 4 \times ESR \times (2\pi F)^2 \times (C_0 + C_L)^2$$

where:

- ESR is the equivalent series resistance
- C_0 is the crystal shunt capacitance
- C_L is the crystal nominal load capacitance.
- F is the crystal nominal oscillation frequency

For example, to design the oscillation loop for the HSE oscillator embedded in an STM32F1 microcontroller with a transconductance value (g_m) of 25 mA/V, we choose a quartz crystal from Fox, with the following characteristics:

- Frequency = 8 MHz
- C_0 = 7 pF
- C_L = 10 pF
- ESR = 80 Ω

To check if this crystal oscillates, let us calculate g_{mcrit}:

$$g_{mcrit} = 4 \times 80 \times (2 \times \pi \times 8 \times 10^{6})^{2} \times (7 \times 10^{-12} + 10 \times 10^{-12})^{2} = 0.23 \text{ mA/V}$$

Calculating the gain margin gives:

$$gain_{margin} = \frac{g_m}{g_{mcrit}} = \frac{25}{0.23} = 107$$

The gain margin is sufficient to start the oscillation and the $gain_{margin}$ > 5 condition is met. The oscillator is expected to reach stable oscillation after the typical delay specified in the datasheet.

If an insufficient gain margin is found ($gain_{margin}$ < 5), the oscillation can start when designing and testing the final application, but this does not guarantee that the oscillation starts in operating conditions. It is highly recommended that the selected crystal has a gain margin higher than or equal to 5 (try to select a crystal with a lower ESR and/or a lower C_L).

In a second example of the case where the maximal critical crystal transconductance is given, the HSE oscillator embedded in STM32G0 microcontrollers has G_m = 1.5 mA/V. g_{mcrit} for the implemented oscillator must stay below this value. The Fox quartz crystal described above respects this condition.

The conversion between the oscillator transconductance (g_m) and the oscillation loop maximal critical transconductance ($G_{m_crit_max}$) is given by $G_{m_crit_max} = g_m / 5$.

Note: Before any verification, the crystal chosen must vibrate at a frequency that respects the oscillator frequency range given in the STM32 datasheet.

3.5 Drive level and external resistor calculation

The drive level (DL) and external resistor value (R_{Ext}) are closely related, and are addressed in the same section.

3.5.1 Calculating the drive level

The drive level is the power dissipated in the crystal. It must be limited, otherwise the quartz crystal can fail because of excessive mechanical vibrations. The maximum drive level is specified by the crystal manufacturer, usually in mW. Exceeding this value can lead to crystal damage, or to a shorter device lifetime.

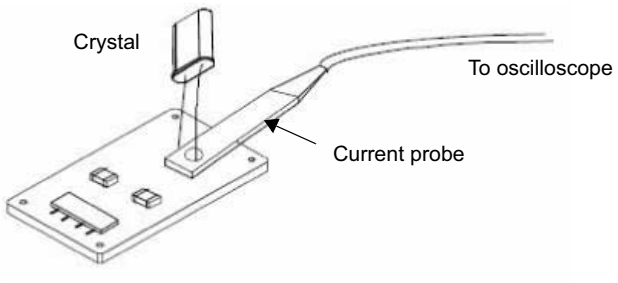
The drive level is given by the formula: $DL = ESR \times I_Q{}^2$, where:

- ESR is the equivalent series resistor (specified by the crystal manufacturer):

$$ESR = R_m \times \left(1 + \frac{C_0}{C_L}\right)^2$$

- I_Q is the current flowing through the crystal in RMS. This current can be displayed on an oscilloscope as a sine wave. The current value can be read as the peak-to-peak value (I_{PP}). When using a current probe (as shown in *Figure 7*), the voltage scale of an oscilloscope may be converted into 1 mA / 1 mV.

Figure 7. Current drive measurement with a current probe



So, as described previously, when tuning the current with the potentiometer, the current through the crystal (assuming it is sinusoidal) does not exceed I_{Qmax} RMS, given by:

$$I_{Qmax}RMS = \sqrt{\frac{DL_{max}}{ESR}} = \frac{I_{Qmax}PP}{2\sqrt{2}}$$

Therefore, the current through the crystal (peak-to-peak value read on the oscilloscope) should not exceed a maximum peak-to-peak ($I_{Qmax}PP$) equal to:

$$I_{Qmax}PP = 2 \times \sqrt{\frac{2 \times DL_{max}}{ESR}}$$

Hence, the need for an external resistor R_{Ext} (refer to *Section 3.5.3*) when I_Q exceeds $I_{Qmax}PP$. The addition of R_{Ext} becomes mandatory, and is added to ESR in the expression of I_{Qmax}.

3.5.2 Another drive level measurement method

The drive level can be computed as DL= I^2_{QRMS} × ESR (I_{QRMS} is the RMS AC current).

This current can be calculated by measuring the voltage swing at the amplifier input with a low-capacitance oscilloscope probe (no more than 1 pF). The amplifier input current is negligible with respect to the current through C_{L1}, so we can assume that the current through the crystal is equal to the current flowing through C_{L1}. Therefore, the RMS voltage at this point is related to the RMS current by $I_{QRMS} = 2\ \pi\ F\ x\ V_{RMS}\ x\ C_{tot}$, with:

- F = crystal frequency
- $V_{RMS} = \frac{V_{pp}}{2\sqrt{2}}$, where V_{pp} is the peak-to-peak voltage measured at C_{L1} level
- $C_{tot} = C_{L1} + (C_s / 2) + C_{probe}$ where:
  - C_{L1} is the external load capacitance at the amplifier input
  - C_s is the stray capacitance
  - C_{probe} is the probe capacitance

Therefore, $DL = \frac{ESR \times (\pi \times F \times C_{tot})^2 \times (V_{pp})^2}{2}$.

This value must not exceed the drive level specified by the crystal manufacturer.

Note: Use special care when measuring voltage swing at LSE input, as it is very sensitive to load capacitance. It is recommended to use a 0.1 pF input capacitance probe.

3.5.3 Calculating the external resistor

The role of this resistor is to limit the drive level of the crystal. With C_{L2}, it forms a low-pass filter that forces the oscillator to start at the fundamental frequency and not at overtones (prevents the oscillator from vibrating at the odd harmonics of the fundamental frequency). If the power dissipated in the crystal is higher than the value specified by the crystal manufacturer, the external resistor R_{Ext} becomes mandatory to avoid overdriving the crystal. If the power dissipated in the selected quartz is lower than the drive level specified by the crystal manufacturer, the insertion of R_{Ext} is not recommended, and its value is then 0 Ω.

An initial estimation of R_{Ext} is obtained by considering the voltage divider formed by R_{Ext} and C_{L2}. Thus, the value of R_{Ext} is equal to the reactance of C_{L2}.

Therefore, $R_{Ext} = 1 / (2\ \pi\ F\ C_{L2})$, and so, with an oscillation frequency of 8 MHz and C_{L2} = 15 pF, we have R_{Ext} = 1326 Ω.

The recommended way for optimizing R_{Ext} is to first choose C_{L1} and C_{L2} as explained before, and to connect a potentiometer in the place of R_{Ext}. The potentiometer should be initially set to be approximately equal to the capacitive reactance of C_{L2}. It should then be adjusted as required, until an acceptable output and crystal drive level are obtained.

Caution: After calculating R_{Ext}, it is recommended to recalculate the gain margin (refer to *Section 3.4*) to make sure that the addition of R_{Ext} has no effect on the oscillation condition. The value of $R_{Ext\ must}$ be added to ESR in the expression of g_{mcrit}, and $g_m \gg g_{mcrit}$ must also remain true:

$$g_m \gg g_{mcrit} = 4 \times (ESR + R_{Ext}) \times (2\ \pi\ F)^2 \times (C_0 + C_L)^2$$

Note: If R_{Ext} is too low, there is a considerable increase of the power dissipation by the crystal. If, on the other hand, R_{Ext} is too high, there is no oscillation.

3.6 Startup time

This is the time required by the oscillation to start and then build up, until it reaches a stable oscillation phase. The startup time depends, among other factors, on the Q-factor of the resonator used. If the oscillator is paired with a quartz-crystal resonator characterized by its high Q-factor, the startup time is higher when ceramic resonators are used (these are known for their poor Q-factor, compared to quartz-crystal resonators). The startup time also depends upon the external components, C_{L1} and C_{L2}, and on the crystal frequency. The higher the crystal nominal frequency, the lower the startup time. In addition, startup problems usually arise because the gain margin is not properly dimensioned (as explained previously). This is caused either by C_{L1} and C_{L2} being too small or too large, or by the ESR being too high.

As an example, an oscillator paired with a few MHz nominal frequency crystal resonator typically starts up after a delay of a few ms.

The startup time of a 32.768 kHz crystal ranges between 1 and 5 s.

3.7 Crystal pullability

Crystal pullabilty, also known as crystal sensitivity, measures the impact of small variations of the load capacitance seen by the crystal on the oscillation frequency shifting. This parameter has more importance when dealing with low-speed oscillators, as they are used to clock time-keeping functions (such as real-time clock).

When the final application is still in the design stage, the influence of this parameter on the low-speed oscillator accuracy (and consequently on all the time-keeping functions clocked by this oscillator) is not obvious. This is because the designer fine tunes the load capacitors until the desired oscillation frequency is obtained. When the design reaches production stage it is frozen, and all the passive components including the load capacitors have their values well defined. Any change of the load capacitance induces a shift of the oscillation frequency.

Changes in the capacitive load (C_L) seen by the crystal can be thought of as due to inadequate operation environment, and only happening when the final design is not properly operated. In practice, this is not true since changes of the load capacitance are rather frequent and must be taken into account by the designer. The main contributors to the capacitive load (C_L) seen by the oscillator are

- the capacitance of the load capacitors C_{L1} and C_{L2}
- the stray capacitance of the PCB paths
- the parasitic capacitance of the oscillator pins.

Any change on the capacitances listed above directly shifts the oscillation frequency. When the design is in production stage, many of these capacitance values cannot be accurately controlled. Selecting a crystal with low pullability limits the influence of such production uncertainties on the final oscillation frequency accuracy.

Generally speaking, the higher the load capacitance of a crystal, the lower its pullability. As an example, let us consider a crystal with a pullability of 45 PPM/pF. To fine-tune the oscillation frequency, this crystal is loaded by two C0G ceramic capacitors (with a ± 5% tolerance of their nominal value), C_{L1} and C_{L2}, with the same 7 pF capacitance.

From the crystal point of view, the two load capacitors are mounted in series, which means that their contribution to C_L is (C_{L1} = C_{L2}) / 2. The tolerance on their contribution to C_L

remains the same, and is equal to ± 5%. If we consider that all the remaining contributors to the C_L are maintained to their nominal values at design stage (to assess the frequency shift magnitude induced only by load capacitor tolerances), then the load capacitance seen by the crystal (C_L) either decreases by 0.175 pF, or increases by the same value. This induces an oscillation shift of:

$0.175\ pF \times 45\ PPM / pF = \sim 7.8\ PPM$ (~0.7 s/day for a time-keeping function such as RTC)

The above example shows that lower pullability results in lower impact of small load capacitance deviation on the frequency shifting. Crystal pullability is an important factor when defining the final application PPM budget.

$$Pullability_{(PPM/\ pF)} = \frac{C_m \times 10^6}{2 \times (C_0 + C_L)^2}$$

where

- C_m is the crystal motional capacitance (in pF)
- C_0 is the crystal shunt capacitance (in pF)
- C_L is the crystal nominal load capacitance (in pF)

The following sections give a more detailed description on how to calibrate the oscillation frequency, and how to estimate the final accuracy uncertainty (PPM) budget.

3.8 Safety factor

3.8.1 Definition

Resonators (such as crystal resonators) undergo aging effects that manifest themselves over time in deviations of resonator parameters from the values defined by the specifications. Among the impacted parameters there is the resonator ESR, whose value depends upon the environment conditions, such as moisture and temperature. The oscillator transconductance depends upon the power supply voltage and upon the temperature.

The safety factor parameter enables to determine the oscillator safe operation under the operating conditions and during the application life. It measures the ability of the oscillator not to fail under operating conditions.

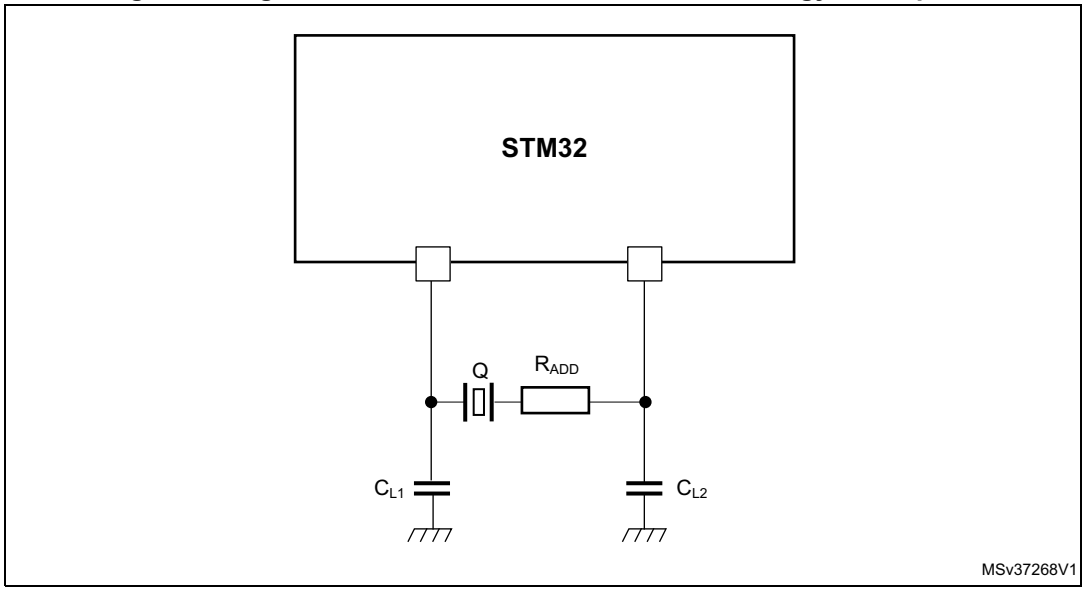
The safety factor is defined as the ratio between the oscillator negative resistance and its ESR:

$$S_f = \frac{\text{Oscillator negative resistance}}{\text{Crystal ESR}} = \frac{R_{ADD} + \text{Crystal ESR}}{\text{Crystal ESR}}$$

3.8.2 Measurement methodology

To measure the oscillator negative resistance, a resistance is added in series to the resonator, as indicated in *Figure 8*.

Figure 8. Negative resistance measurement methodology description



The oscillator negative resistance is the value of the smallest series resistance R_{ADD} preventing the oscillator from starting up successfully.

In practice, this value is set by conducting a series of experiments in which the value of the series resistance is slightly increased compared to the previous experiment. The sequence stops when the oscillator is unable to start correctly. The oscillator negative resistance is equal to the value of the added series resistance.

3.8.3 Safety factor for STM32 and STM8 oscillators

Table 4 summarizes the safety factor (S_f) for oscillators embedded in STM32 and STM8 devices. For the LSE oscillator, the oscillation is considered safe for $S_f \geq 3$, while for the HSE oscillator this is true when $S_f \geq 5$.

Table 4. Safety factor (S_f) for STM32 and STM8 oscillators(1)

Safety factor (S_f)	Assurance level	
	HSE	LSE
$S_f \geq 5$	Safe	Very safe
$3 \leq S_f < 5$	Not safe	Safe
$S_f < 3$		Not safe

1. Safe and very safe oscillations are shown in green, unsafe oscillation in yellow.

3.9 Oscillation modes

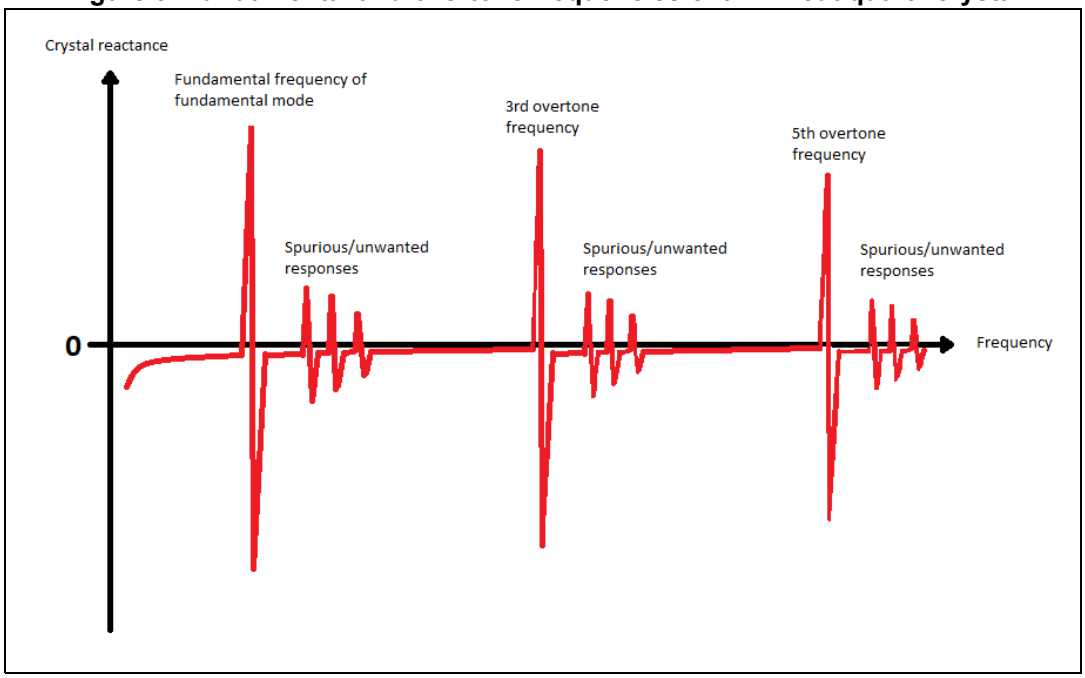
3.9.1 What are fundamental and overtone modes?

Equation *(4)* gives the oscillation frequency F_p of a crystal, which depends on the series resonant frequency F_s for which the crystal impedance is null. The oscillator is said to operate in fundamental mode when vibrating around F_p.

Fs (and hence Fp) depend upon the parameters of the crystal theoretical model illustrated in *Figure 1*. These parameters, given by the crystal manufacturer, define the frequency for which the crystal is designed to oscillate around the fundamental frequency.

In real life, an AT-cut quartz crystal impedance reaches a zero value for several frequencies, which correspond to the odd multiples of its fundamental vibration frequency. A crystal can also vibrate around one of those odd multiples, these are the overtone oscillation modes. *Figure 9* represents the cancellation of an AT-cut crystal impedance for the fundamental frequency, its following odd multiples (third and fifth overtones are represented), as well as some spurious frequencies.

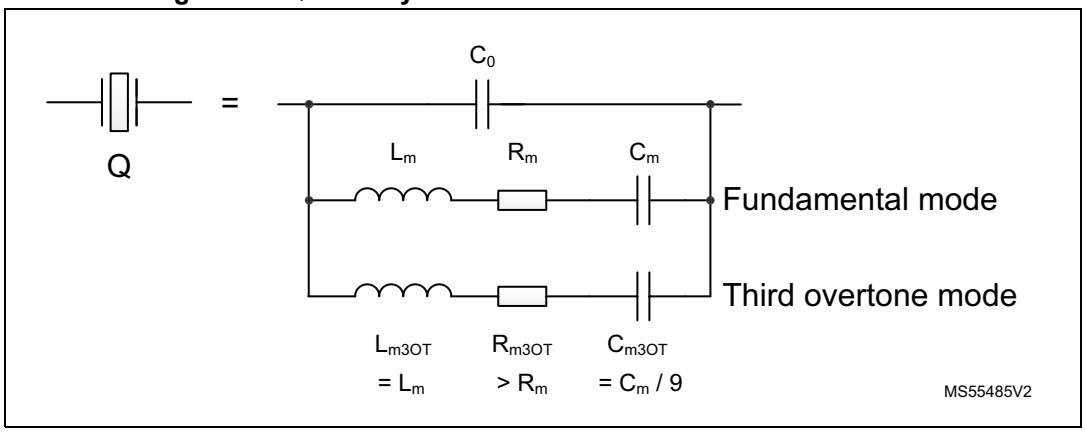
Figure 9. Fundamental and overtone frequencies of an AT-cut quartz crystal



Note: AT-cut quartz corresponds to most of the crystals to use with HSE. For LSE, tuning fork crystals can be used, but they do not show the same oscillation mode possibilities (Figure 9 is not valid for them). In this part, we consider an AT-cut quartz crystal when referring to a crystal.

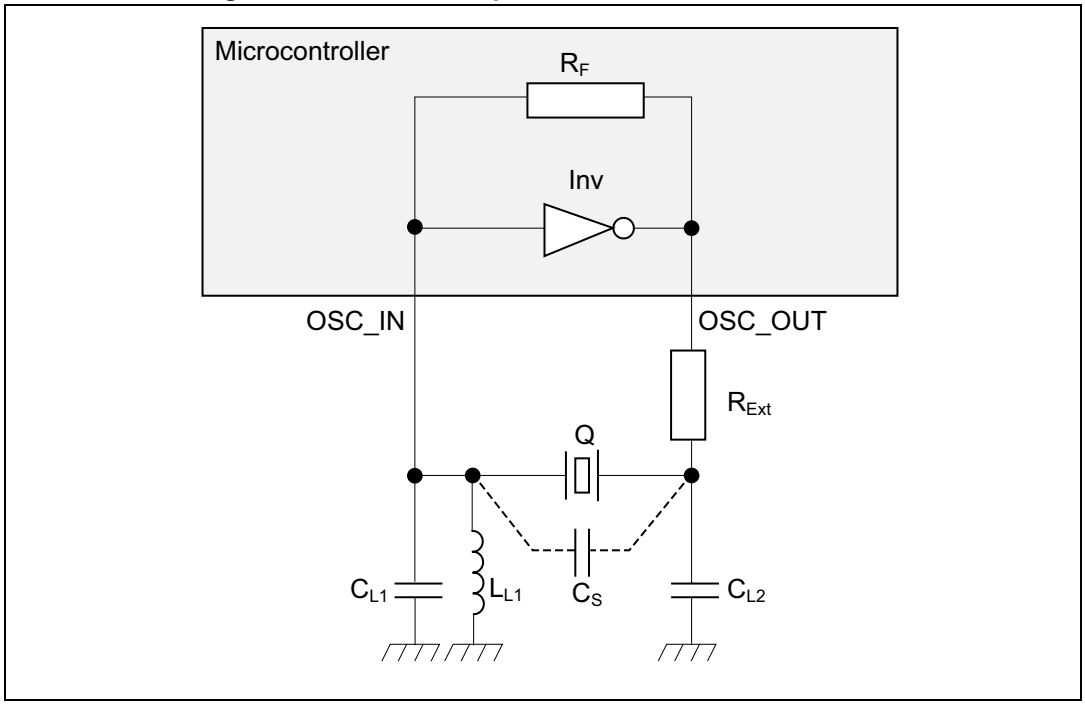
This multiple-time cancellation is because a more accurate quartz crystal theoretical model shows an RLC branch for each one of its overtone modes, as illustrated in *Figure 10*.

Figure 10. Quartz crystal theoretical model with third overtone



For example, it is possible to use the third overtone mode by implementing the oscillator as shown in *Figure 11*, to suppress the fundamental frequency (theoretically each overtone mode can be selected by suppressing the previous ones).

Figure 11. Oscillator implementation for third overtone



3.9.2 Third overtone mode: pros and cons

Because of the thickness, the crystals designed for a high frequency fundamental mode are very expensive, requiring high-end cutting technologies and a lot of caution for implementation. Practically, it becomes impossible to operate in fundamental mode for a frequency above 50 MHz. This is why most of the high frequency crystals are designed to work in the third overtone mode (it is possible to cut the crystal for a frequency three times lower than the one it oscillates at).

The model for a crystal operating in third overtone mode (*Figure 11*) shows a resistance R_m approximately three times higher and a capacitance C_m nine times lower than those associated with the fundamental mode.

For the third overtone mode, these differences mean a higher Q-factor since the quality factor for an RC series circuit is 1 / ωRC (less energy loss, more stable performances, better jitter, and lower pullability, see *Section 3.7*). A lower pullability means a lower frequency shift when the application is deployed in the field, at the expense of lower tunability of the oscillation frequency.

3.9.3 Considerations for crystals interfaced with STM32 products

The oscillators integrated in the STM32 products have been validated for use in the fundamental mode, respecting the implementation of *Figure 5*. If a third overtone crystal is used with this implementation, the theory indicates that it does not start vibrating at the third harmonic frequency, but at the fundamental one.

Note: The startup mode of an oscillator can even involuntarily balance between the two modes if its external components have not been chosen according to what indicated in this document.

4 Guidelines to select a suitable crystal and external components

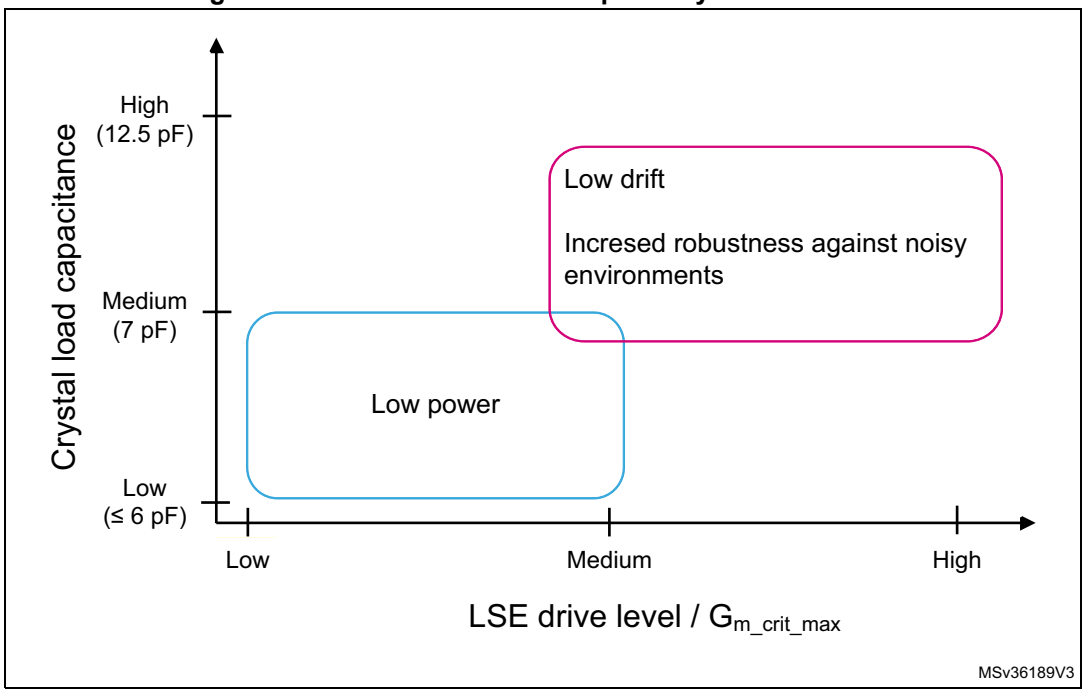
4.1 Low-speed oscillators embedded in STM32 MCUs/MPUs

The low-speed resonator market provides a wide range of crystal resonators. Selecting the most adequate one for a given design depends on many parameters. The most important parameters to be taken into account (only technical factors are listed) are:

- Crystal size or footprint
- Crystal load capacitance (C_L)
- Oscillation frequency offset (PPM)
- Startup time

A trade-off between the above parameters must be found, depending on the key design criteria. *Figure 12* shows that the resonators available on the market can be divided into two categories, depending upon the above-mentioned factors and trade-offs.

Figure 12. Classification of low-speed crystal resonators



A resonator with a relatively high load-capacitance (such as 12.5 pF) requires more power for the oscillator to drive the oscillation loop at the resonator nominal frequency. Designs targeting low power consumption (for example, RTC application powered by coin-batteries requiring very long autonomy) are consequently more likely to use resonators with relatively small load capacitance. On the other side, big load capacitance resonators have a much smaller pullabilty compared to resonators with small load capacitance. As a result, designs without severe constraints on power consumption tend to use big load capacitance crystals to reduce pullability.

One of the key areas where crystal resonators are massively used is the hand-held and wearable appliance consumer market (such as smartphones, Bluetooth® kits). For this

market segment, the crystal size is of critical importance. However, it is widely known that small-footprint crystals come with high crystal ESR. The choice may be harder if the target design has severe constraints in terms of power consumption (the usual scenario). In this case, choose a crystal with a load capacitance as small as possible to optimize power consumption even if this compromises pullabilty. In addition, crystals with high ESR may have a slightly longer startup time. If there are no constraints on crystal size, then it is recommended to choose a crystal with the smallest possible ESR.

In noisy environments (almost always the case for industrial applications), if there are no constraints on power consumption, it is recommended to choose crystals with high load capacitance. These crystals require a high-drive current from the oscillator, but are more robust against noise and external perturbations. Another advantage is that the design pullability is minimized.

Depending on the device used, all the resonator families listed below can be compatible with your design, or only some of them. STM32 devices embed two types of low-speed oscillator (LSE):

- Constant gain

  This type of LSE oscillator features a constant gain, which makes them compatible only with a few crystal groups mentioned above. For example, LSE oscillators embedded in STM32F2 and STM32L1 MCUs target designs with severe power consumption constraints. The selected crystal should consequently have a low load capacitance and a moderate ESR. LSE oscillators embedded in STM32F1 MCUs target crystal resonators with moderate ESR and moderate load capacitance.

- Configurable gain

  The main advantage of LSE oscillators belonging to this family is the compatibility with a large number of crystals. Almost no constraint comes by the device embedding this kind of oscillator. The large list of compatible resonator crystals allows the designer to focus on design constraints (such as power consumption, footprint) when selecting a compatible resonator. These oscillators are divided into two categories:

  – Dynamically (on-the-fly) modifiable gain LSE oscillators

    The gain of this type of LSE oscillators can be changed either before starting the oscillator or after enabling it.

  – Statically modifiable gain LSE oscillators

    The gain can be changed only when the LSE oscillator is turned off. If the oscillator transconductance has to be increased or decreased, the LSE must be turned off first.

Table 5 gives the list of low-speed oscillators (LSE) embedded in STM32 devices.

Caution: When the gain is modified statically or on-the-fly, the calibration of the oscillation frequency must be readjusted to estimate the final accuracy uncertainty (PPM) budget.

Caution: In STM32F0 and STM32F3 MCUs, High drive mode (g_m = 25 µA/V) must be used only with 12.5 pF crystals, to avoid saturating the oscillation loop and causing a startup failure. When used with a low C_L crystal (for example 6 pF), the oscillation frequency jitters and duty cycle can be distorted.

Table 5. LSE oscillators embedded into STM32 MCUs/MPUs(1)

Series	Drive level	$g_{m\ (min)}$	$G_{m_crit_max}$	Unit
C0	Medium high	8.5	1.7	µA/V
	High	13.5	2.7	
F0, F3	Low	5	1.0	
	Medium low	8	1.6	
	Medium high	15	3	
	High	25	5	
F1, T	Not available	5	1	µA/V
F2, F4_g1(2)		2.8	0.56	
F4_g2(3)	Low	2.8	0.56	µA/V
	High	7.5	1.5	
F7	Low	2.4	0.48	µA/V
	Medium low	3.75	0.75	
	Medium high	8.5	1.7	
	High	13.5	2.7	
L1	Not available	3	0.6	µA/V
G0, G4 H7 L0, L4, L4+, L5 MP1, MP2 N6 U0, U3, U5(4) WB, WB0, WBA(5), WL	Low	2.5	0.5	µA/V
	Medium low	3.75	0.75	
	Medium high	8.5	1.7	
	High	13.5	2.7	
C5, H5, G5, H7P	Medium low	3.75	0.75	
	Medium high	8.5	1.7	
	High	13.5	2.7	

1. Color code:
   - Light blue: LSE oscillators with transconductance modifiable on the fly (dynamically)
   - Yellow: LSE oscillators with non-modifiable transconductance
   - Gray: LSE oscillators with statically-modifiable transconductance
2. STM32F4 series with LSE generation 1 (STM32F401/405/407/415/417/427/429/437/439xx MCUs featuring LSE oscillators with non modifiable transconductance).
3. STM32F4 series with LSE generation 2 (STM32F410/411/412/413/423/446/469/479xx MCUs featuring LSE oscillators with statically modifiable transconductance).
4. STM32U575/585 rev. X devices do not support low drive mode.
5. STM32WBA devices do not support low drive mode.

4.2 How to select an STM32-compatible crystal

This section describes the procedure recommended to select suitable crystal/external components. The procedure is based on the following steps:

Step 0: Choose a fundamental mode designed resonator

Choose a fundamental mode designed resonator (as explained in *Section 3.9*, the STM32 oscillators are validated to work with resonator vibrating in fundamental mode and while using the Pierce oscillator circuitry presented in *Figure 5*), and make sure that the resonator chosen is designed to work in fundamental mode.

Step 1: Check the resonator compatibility with the selected STM32

To check the compatibility between the selected crystal and the STM32 MCU/MPU, first identify the procedure to follow among the two described in *Section 3.4*. The decision must be made based on the oscillator specification provided in the datasheet.

- If the oscillator transconductance parameter is specified, then apply the second procedure. Ensure that the gain margin ratio is higher than five (x5) to make sure that the crystal is compatible with the selected STM32 part.
- If $G_{m_crit_max}$ is specified instead, make sure that gmcrit for the oscillation loop is smaller than the specified $G_{m_crit_max}$ value.

Step 2: Determine the capacitance value of the load capacitors C_{L1} and C_{L2}

To determine the correct capacitance values for C_{L1} and C_{L2} load capacitors, apply the formula specified in *Section 3.3*. The values obtained are approximations of the exact capacitances to be used. In a second phase, to fine-tune the values of the load capacitors, go through a series of experimental iterations, until the right capacitance values are found.

During the experimental phase, use a standard crystal, one whose PPM drift is well known when it is loaded by the crystal nominal load capacitance (C_L). This kind of crystal can be provided by the manufacturer upon request. After this crystal has been chosen, calculate its oscillation frequency ($F_{standard}$) when the crystal is loaded by its nominal load capacitance. This frequency is given by the formula:

$$F_{standard} = F_{nominal} \times \left(PPM_{standard} / \ 10^6 \right)$$

where:

- $F_{standard}$ is the standard crystal oscillation frequency when it is loaded by its nominal load capacitance
- $F_{nominal}$ is the oscillation nominal frequency specified in the crystal datasheet
- $PPM_{standard}$ is the oscillation frequency drift of the standard crystal, as characterized by the crystal manufacturer

When $F_{standard}$ is computed, go through the following sequence:

1. Make the first experimental iteration with C_{L1} and C_{L2} capacitance values determined by calculation:
   - If the oscillation frequency is equal to $F_{standard}$, C_{L1} and C_{L2} are the correct capacitances. The user can therefore skip substeps *2* and *3*.
   - If the oscillation frequency is slower than $F_{standard}$ go to substep *2*, otherwise execute substep *3*.
2. For this experimental iteration, decrease C_{L1} and C_{L2} capacitance values, measure again the oscillation frequency, and compare it to $F_{standard}$:
   - If the oscillation frequency is slower than $F_{standard}$, execute substep *2*, otherwise execute substep *3*.
   - If the oscillation frequency is almost equal to $F_{standard}$, use the latter C_{L1} and C_{L2} capacitance values.
3. For this experimental iteration, increase C_{L1} and C_{L2} capacitance values, measure again the oscillation frequency, and compare it to $F_{standard}$:
   - If the oscillation frequency is slower than $F_{standard}$, execute substep *2*, otherwise execute substep *3*.
   - If the oscillation frequency is almost equal to $F_{standard}$, use the latter C_{L1} and C_{L2} capacitance values.

Step 3: Check the safety factor of the oscillation loop

The safety factor must be assessed as described in *Section 3.8* to ensure a safe oscillation of the oscillator under operating conditions.

Note: Many crystal manufacturers can check device/crystal pairing compatibility upon request. If the pairing is judged valid, they can provide a report including the recommended C_{L1} and C_{L2} values, as well as the oscillator negative resistance measurement. In this case steps 2 and 3 can be skipped.

Step 4: Calculate the drive level and external resistor

Compute the drive level (DL) (see *Section 3.5*) and check if it is greater or lower than $DL_{crystal}$:

- If $DL < DL_{crystal}$, no need for an external resistor (a suitable crystal has been found).
- If $DL > DL_{crystal}$, the user should calculate R_{Ext} to have: $DL < DL_{crystal}$. The user should then recalculate the gain margin taking R_{Ext} into account.
  If gain margin > 5, a suitable crystal has been found. If not, then this crystal does not work, another one must be chosen. Return to *Step 1: Check the resonator compatibility with the selected STM32* to run the procedure for the new crystal.

Step 5 (optional): Calculate the PPM accuracy budget

Use the following formula to estimate the PPM accuracy budget for the application:

$$PPM_{Budget} = PPM_{crystal} + Deviation(C_L) \times Pullability_{crystal}$$

where:

- PPM_{Budget} is the estimated accuracy for the oscillation frequency
- $PPM_{crystal}$ is the crystal PPM accuracy specified in the datasheet

Deviation (C_L) is expressed in pF. It measures the deviation of the load capacitance (C_L) due to tolerances on load capacitor values and the variation of the stray capacitance (C_S) due to PCB manufacturing process deviation.

Pullabilty is expressed in PPM / pF (refer to *Section 3.7*).

Note: The PPM budget calculated above does not take into account the temperature variation, which can make the PPM budget bigger.

5 Recommended resonators for STM32 MCUs/MPUs

5.1 STM32-compatible high-speed resonators

The high-speed oscillator (HSE) embedded into STM32 products[a] is compatible with almost all the resonators available on the market. The recommended resonators are provided by a wide range of manufacturers, including:

- ABRACON
- ECS (www.ecsxtal.com)
- EPSON (http://www5.epsondevice.com)
- KYOCERA
- Micro Crystal
- muRata (www.murata.com)
- NDK (http://www.ndk.com)
- RIVER (http://www.river-ele.co.jp)

Several KDS tools are available to select the more recent and high-demand crystals, among them the STM32 Crystal Selection Tool from ECS, the IC Matching Information provided by NDK, and IC manufacture Information of KDS.

Compatible resonators come with various frequencies and technologies (ceramic resonators and quartz-crystal resonators working in fundamental mode are all compatible with the HSE oscillator embedded in STM32 MCUs/MPUs). *Table 6* summarizes the supported frequency ranges.

Table 6. HSE oscillators embedded in STM32 MCUs/MPUs

Series	F0 F3	F1 T	F2	F4	F7	L0	L1	C0 L4, L4+ L5 H7 G0, G4 MP1 U0	G5 H7P C5 H5 U3 U5	MP2	N6	Unit
Frequency range	4 - 32	4 - 16	4 - 25	4 - 26	4 - 26	1 - 25	1 - 24	4 - 48	4 - 50	16 - 48	16 - 48	MHz
$g_{m\ (min)}$	10	25	5	5	5	3.5	3.5	7.5	7.5	9.75	9.57	mA/V
$G_{m_crit_max}$	2	5	1	1	1	0.7	0.7	1.5	1.5	1.95	1.95	

5.2 STM32-compatible low-speed resonators

Table 7 contains a not exhaustive list (only the compatible resonator part numbers checked by ST are included) of low-speed quartz-crystal 32.768 kHz resonators that are either compatible with the whole STM32 portfolio, or with a subset.

a. This is not applicable for STM32WB, STM32WB0, STM32WBA and STM32WL series due to the RF constraints. For information about HSE oscillator compatibility with these devices, refer to *Precise HSE frequency and startup time tuning for STM32 wireless MCUs* (AN5042), available on www.st.com.

Different footprints are provided to facilitate crystal selection, even if there are geometric constraints for the final application.

Table 7. Recommended crystal / MEMS resonators for the LSE oscillator in STM32 products

Package size	Manufacturer	Quartz reference Part number	ESR max (kΩ)	C_0 (pF)	C_L (pF)	g_{mcrit}[1] (µA/V)	STM32 series compatibility[2][3]
1.2 x 1.0 mm^2	RIVER	TFX-05X	90	1.5	5	0.6447	C0, F0, F1, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					7	1.1026	C0, F0, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					9	1.6824	C0, F0, F3, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					12.5	2.9910	F0, F3
	SII	SC-12S (2 terminals)	90	1.4	6	0.8356	C0, F0, F1, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					7	1.0768	C0, F0, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					9	1.6506	C0, F0, F3, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					12.5	2.9484	F0, F3
	ECS	ECS-.327-6-1210-TR	90	1.1	6	0.7692	C0, F0, F1, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-7-1210-TR			7	1.0012	C0, F0, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-9-1210-TR			9	1.5567	C0, F0, F3, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-12.5-1210-TR			12.5	2.8225	F0, F3
		ECS-.327-5-1210B-N-TR	80	1.5	5	0.5731	C0, F0, F1, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-7-1210B-N-TR			7	0.9800	C0, F0, F1, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-9-1210B-N-TR			9	1.4955	C0, F0, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-12.5-1210B-N-TR			12.5	2.6587	C0, F0, F3, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
	Würth Elektronik	830107834801	90	1.4	6	0.8356	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		830108211801			7	1.0767	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		830108091501			12.5	2.9484	F0, F3

Table 7. Recommended crystal / MEMS resonators for the LSE oscillator in STM32 products (continued)

Package size	Manufacturer	Quartz reference Part number	ESR max (kΩ)	C_0 (pF)	C_L (pF)	g_{mcrit}[1] (µA/V)	STM32 series compatibility[2][3]
1.2 x 1.0 mm²	ABRACON	ABS04W-32.768 KHz 4 pF	80	1.5	4	0.4103	C0, F0, F1, F2, F3, F4, L0, L1, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ABS04W-32.768 KHz 6 pF			6	0.7630	C0, F0, F1, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ABS04W-32.768 KHz 9 pF			9	1.4955	C0, F0, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ABS04W-32.768 KHz 12.5 pF			12.5	2.6587	C0, F0, F3, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
1.6 x 1.0 mm²	Micro Crystal	CM9V-T1A / CM9V-T1A 0.3	90	1.4	4	0.4449	C0, F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					6	0.8356	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					7	1.0768	C0, F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					9	1.6506	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					12.5	2.9484	F0, F3
	ECS	ECS-.327-6-16-TR3		1.3	6	0.8132	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-7-16-C-TR			7	1.0513	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-9-16-TR			9	1.6190	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-12.5-16-TR			12.5	2.9062	F0, F3
	NDK	NX1610SA 32.768 kHz EXS00A-MU00658		1.3	6	0.8132	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		NX1610SA 32.768 kHz EXS00A-MU01367			12.5	2.9062	F0, F3
		NX1610SE 32.768 kHz EXS00A-MU01501	60[4]	1.55	6	0.5799	C0, F0, F1, F2, F3, F4, L0, L1, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		NX1610SE 32.768 kHz EXS00A-MU01500			7	0.7437	C0, F0, F1, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		NX1610SE 32.768 kHz EXS00A-MU01499			9	1.1323	C0, F0, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		NX1610SE 32.768 kHz EXS00A-MU01498			12.5	2.0083	C0, F0, F3, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5

Table 7. Recommended crystal / MEMS resonators for the LSE oscillator in STM32 products (continued)

Package size	Manufacturer	Quartz reference Part number	ESR max (kΩ)	C_0 (pF)	C_L (pF)	g_{mcrit}[1] (µA/V)	STM32 series compatibility[2][3]
1.6 x 1.0 mm^2	SII	SC-16S	90	1.2	6	0.7910	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					12.5	2.8642	F0, F3
	EPSON	FC1610AN 32.768000 kHz 9			9	1.5877	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		FC1610AN 32.768000 kHz 12.5			12.5	2.8642	F0, F3
	CITIZEN	CM1610H			6	0.7910	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					7	1.0261	C0, F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					9	1.5877	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					12.5	2.8642	F0, F3
	ECS	ECS-.327-4-16R-TR	60	1,5	4	0,3077	C0, F0, F1, F2, F3, F4, L0, L1, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-6-16R-TR			6	0,5722	C0, F0, F1, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-9-16R-TR			9	1,1216	C0, F0, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-12.5-16R-TR			12,5	1,994	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
	Würth Elektronik	830108214001	90	1,2	4	0.4126	C0, F0, F1, F2, F3, F4, L0, L1, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		830066431			7	1.0261	C0, F0, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		830066198			9	1.5876	C0, F0, F3, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		830065253			12,5	2.8641	F0, F3
	ABRACON	ABS05-32.768 kHz 9 pF	90	1.3	9	1.6190	C0, F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ABS05-32.768 kHz			12.5	2.9062	F0, F3
		ABS05W-32.768 kHz-D	70	2	4	0.4272	C0, F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5

Table 7. Recommended crystal / MEMS resonators for the LSE oscillator in STM32 products (continued)

Package size	Manufacturer	Quartz reference Part number	ESR max (kΩ)	C_0 (pF)	C_L (pF)	g_{mcrit}[1] (µA/V)	STM32 series compatibility[2][3]
1.6 x 1.0 mm^2	RIVER	TFX-04	90	1.3	5	0.6056	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					7	1.0513	C0, F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					9	1.6190	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					12.5	2.9062	F0, F3
		TFX-04C	60	1.5	5	0.4298	C0, F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					7	0.7350	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					9	1.1216	C0, F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					12.5	1.9940	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
2.0 x 1.2 mm^2	ABRACON	ABS06-107-32.768kHz-T	80	1.5	4	0.4103	C0, F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
	ECS	ECS-.327-6-12-TR	90	1.3	6	0.8312	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-7-12-TR			7	1.0513	C0, F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-9-12-TR			9	1.6190	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-12.5-12-TR			12.5	2.9062	F0, F3
		ECS-.327-CDX-1082	80	1.5	4	0.4103	C0, F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-6-12RR-TR	70	1.7	6	0.7372	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-7-12RR-TR			7	0.8983	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-9-12RR-TR			9	1.3589	C0, F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-12.5-12R-TR			12.5	2.3933	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-6-12R-TR		1.3	6	0.4517	C0, F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-9-12R-TR			9	0.8994	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-12.5-12R-TR			12.5	1.6145	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5

Table 7. Recommended crystal / MEMS resonators for the LSE oscillator in STM32 products (continued)

Package size	Manufacturer	Quartz reference Part number	ESR max (kΩ)	C_0 (pF)	C_L (pF)	g_{mcrit}[1] (µA/V)	STM32 series compatibility[2][3]
2.0 x 1.2 mm^2	Micro Crystal	CM8V-T1A 0.3	90	1.2	4	0.4126	C0, F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					6	0.7910	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					7	1.0261	C0, F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					9	1.5877	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					12.5	2.8642	F0, F3
		CC8V-T1A	80		4	0.3667	C0, F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					6	0.7031	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					7	0.9120	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					9	1.4113	C0, F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					12.5	2.5460	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		CM8V-T1A	70		4	0.3209	C0, F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					6	0.6152	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					7	0.7980	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					9	1.2349	C0, F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					12.5	2.2277	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
	EPSON	FC-12M 32.768000kHz 12.5	90	1.3	12.5	2.9062	F0, F3
		FC-12D 32.768000kHz 7	75	0.8	7	0.7737	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		FC-12D 32.768000kHz 9			9	1.2213	C0, F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		FC-12D 32.768000kHz 12.5			12.5	2.2495	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5

Table 7. Recommended crystal / MEMS resonators for the LSE oscillator in STM32 products (continued)

Package size	Manufacturer	Quartz reference Part number	ESR max (kΩ)	C_0 (pF)	C_L (pF)	g_{mcrit}[1] (µA/V)	STM32 series compatibility[2][3]
2.0 x 1.2 mm^2	RIVER	TFX-03	90	1.3	5	0.6447	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					7	1.0513	C0, F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					9	1.6190	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					12.5	2.9062	F0, F3
	RIVER	TFX-03C	60	1.8	5	0.4704	C0, F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					7	0.7878	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					9	1.1866	C0, F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					12.5	2.0804	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
	NDK	NX2012SA 32.768 kHz EXS00A-MU00527	80	1.3	6	0.7228	C0, F0, F1, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		NX2012SA 32.768 kHz EXS00A-MU00524			7	0.9344	C0, F0, F1, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		NX2012SA 32.768 kHz EXS00A-MU00528			12.5	2.5833	C0, F0, F3, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		NX2012SE 32.768 kHz EXS00A-MU01260	50[4]	1.7	6	0.5026	C0, F0, F1, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		NX2012SE 32.768 kHz EXS00A-MU01259			7	0.6416	C0, F0, F1, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		NX2012SE 32.768 kHz EXS00A-MU01611			9	0.9706	C0, F0, F1, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		NX2012SE 32.768 kHz EXS00A-MU01612			12.5	1.7095	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5

Table 7. Recommended crystal / MEMS resonators for the LSE oscillator in STM32 products (continued)

Package size	Manufacturer	Quartz reference Part number	ESR max (kΩ)	C_0 (pF)	C_L (pF)	g_{mcrit}[1] (µA/V)	STM32 series compatibility[2][3]
2.0 x 1.2 mm^2	SII	SC-20T	75	1	6	0.6231	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					7	0.8138	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					9	1.2717	C0, F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					12.5	2.3177	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		SC-20S	70	1.3	6	0.6325	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					12.5	2.2604	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
	CITIZEN	CM2012H	70	1.3	6	0.6325	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					7	0.8176	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					9	1.2592	C0, F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					12.5	2.2604	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
	Würth Elektronik	830106545501	90	1,7	6	0.9047	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		830105946101			7	1.155	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		830050789			12.5	3.077	F0, F3

Table 7. Recommended crystal / MEMS resonators for the LSE oscillator in STM32 products (continued)

Package size	Manufacturer	Quartz reference Part number	ESR max (kΩ)	C_0 (pF)	C_L (pF)	g_{mcrit}[1] (µA/V)	STM32 series compatibility[2][3]
3.2 x 1.5 mm^2	ABRACON	ABS07L-32.768kHz 7pF	80	1.4	7	0.9751	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ABS07L-32.768kHz 9pF			9	1.6472	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ABS07L-32.768kHz			12.5	2.6208	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ABS07-32.768kHz 6pF	70	1.1	6	0.5815	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ABS07-32.768kHz 7pF			7	0.7596	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ABS07-32.768kHz 9pF			9	1.1869	C0, F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ABS07 32.768kHz			12.5	2.1631	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ABS07-166-32.768kHz-T			7	0.7596	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ABS07-120-32.768kHz-T	60	1.2	6	0.5273	C0, F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ABS07-LR-32.768 kHz-6	50	1.3	6	0.4517	C0, F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
	CITIZEN	CM315D	70	0,95	6	0.5733	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					7	0.7501	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					9	1.1751	C0, F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					12.5	2.1471	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5

Table 7. Recommended crystal / MEMS resonators for the LSE oscillator in STM32 products (continued)

Package size	Manufacturer	Quartz reference Part number	ESR max (kΩ)	C_0 (pF)	C_L (pF)	g_{mcrit}[1] (µA/V)	STM32 series compatibility[2][3]
3.2 x 1.5 mm^2	CITIZEN	CM315E	0,70	0,75	4	0.2678	C0, F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					6	0.5407	C0, F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					8	0.9087	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					9	1.1283	C0, F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					12.5	2.0838	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
	CITIZEN	CM315DL	50	1,3	6	0.4517	C0, F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					7	0.5840	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					9	0.8994	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					12.5	1.6145	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
	Würth Elektronik	830054236	70	1	6	0.5815	C0, F0, F1, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		830009709			7	0.7596	C0, F0, F1, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		830009706			9	1.1869	C0, F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		830009678			12.5	2.1631	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5

Table 7. Recommended crystal / MEMS resonators for the LSE oscillator in STM32 products (continued)

Package size	Manufacturer	Quartz reference Part number	ESR max (kΩ)	C_0 (pF)	C_L (pF)	g_{mcrit}[1] (µA/V)	STM32 series compatibility[2][3]
3.2 x 1.5 mm^2	Micro Crystal	CC7V-T1A CM7V-T1A (low profile)	70	1,2	6	0.6152	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					7	0.7980	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					9	1.2349	C0, F0, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					12.5	2.2277	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		CM7V-T1A 0.3	60	1,4	6	0.5571	C0, F0, F1, F2, F3, F4, L0, L1, L4, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					7	0.7178	C0, F0, F1, F3, F4_g2, L0, L4, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					9	1.1004	C0, F0, F3, F4_g2, L0, L4, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					12.5	1.9656	C0, F0, F3, L0, L4, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		CM7V-T1A	50	1,3	6	0.4517	C0, F0, F1, F2, F3, F4, L0, L1,L4, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					7	0.5840	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					9	0.8994	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					12.5	1.6145	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
	EPSON	FC-135 32.768000 kHz 7	70	1.0	7	0.7596	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		FC-135 32.768000 kHz 9			9	1.1869	C0, F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		FC-135 32.768000 kHz 12.5			12.5	2.1631	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		FC-13A 32.768000 kHz 9		0.9	9	1.1633	C0, F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		FC-13A 32.768000 kHz 12.5			12.5	2.1312	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5

Table 7. Recommended crystal / MEMS resonators for the LSE oscillator in STM32 products (continued)

Package size	Manufacturer	Quartz reference Part number	ESR max (kΩ)	C_0 (pF)	C_L (pF)	g_{mcrit}[1] (µA/V)	STM32 series compatibility[2][3]
3.2 x 1.5 mm^2	EPSON	FC-135R 32.768000 kHz 7	50	1.1	7	0.5562	C0, F0, F1, F3, F4_g2, L0, L1, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		FC-135R 32.768000 kHz 9			9	0.8648	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		FC-135R 32.768000 kHz 12.5			12.5	1.5681	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
	SII	SC-32S	70	1.0	6	0,5815	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					12.5	2.1631	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		SC-32P	50		6	0,4154	C0, F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
					12.5	1.5451	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
	ECS	ECS-.327-6-34QS-TR	70	1,1	6	0.5983	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-7-34QS-TR			7	0.7787	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-9-34QS-TR			9	1.2108	C0, F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-12.5-34QS-TR			12.5	2.1953	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-6-34G-TR		0,75	6	0.5407	C0, F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-12.5-34G-TR			12.5	2.0838	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-6-34S-TR		1,05	6	0.5899	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-12.5-34S-TR			12.5	2.1792	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECX-.327-CDX-1293			12.5	2.1792	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-7-34B-TR			7	0.7691	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-9-34B-TR			9	1.1988	C0, F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-12.5-34B-TR			12.5	2.1792	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-CDX-1128	60	2	6	0.6511	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5

Table 7. Recommended crystal / MEMS resonators for the LSE oscillator in STM32 products (continued)

Package size	Manufacturer	Quartz reference Part number	ESR max (kΩ)	C_0 (pF)	C_L (pF)	g_{mcrit}[1] (µA/V)	STM32 series compatibility[2][3]
3.2 x 1.5 mm^2	ECS	ECS-.327-6-34R-TR	50	1,3	6	0.4517	C0, F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-7-34R-TR			7	0.5840	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-9-34R-TR			9	0.8994	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-12.5-34R-TR			12.5	1.6145	C0, F0, F3, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-6-34RR-TR	40		6	0.3614	C0, F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-9-34RR-TR			9	0.7195	C0, F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		ECS-.327-12.5-34RR-TR			12.5	1.2916	C0, F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
	NDK	NX3215SA 32.768 kHz EXS00A-MU00525	70	1.0	6	0.5815	C0, F0, F1, F2, F3, F4, L0, L1, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		NX3215SA 32.768 kHz EXS00A-MU00523			7	0.7596	C0, F0, F1, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		NX3215SA 32.768 kHz EXS00A-MU00526			12.5	2.1631	C0, F0, F3, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		NX3215SE 32.768 KHz EXS00A-MU00990	40	1.3	6	0.3323	C0, F0, F1, F2, F3, F4, L0, L1, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5
		NX3215SE 32.768 KHz EXS00A-MU00989			12.5	1.2361	C0, F0, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, C5, H5, G5, H7P, H7, N6, WB, WB0, WBA, WL, MP1, MP2, U0, U3, U5

1. As defined in *Section 3.4: Oscillator transconductance*.
2. F4_g1: STM32F4 series with LSE generation 1, corresponds to STM32F401/405/ 407/415/417/427/429/437/439xx MCUs featuring LSE oscillators with non-modifiable transconductance.
3. F4_g2: STM32F4 series with LSE generation 2, corresponds to STM32F410/411/412/413/423/446/469/479xx MCUs, featuring LSE oscillators with statically-modifiable transconductance.
4. Low_ESR: -40 to +85 °C.

Note: STM32U575/585 rev. X devices do not support crystal/MEMS resonators with $C_L \leq 6$ pF.

6 Recommended crystals for STM8AF/AL/S MCUs

6.1 Part numbers of recommended crystal oscillators

Table 8. KYOCERA compatible crystals (not exhaustive list)

Part number	Frequency	ESR max	C_L	Drive level (DL)
CX3225GA8000D0PTVCC	8 MHz	500 Ω	8 pF	200 µW max
CX3225SA8000D0PTVCC				
CX2016SA16000D0GSSCC	16 MHz	200 Ω		
CX2016GR16000D0GTVCC		300 Ω		300 µW max
CX3225CA16000D0PSVCC CX3225GA16000D0PTVCC		100 Ω		200 µW max
CX3225SB16000D0GSSCC		80 Ω		100 µW max
CX3225SA16000D0PTVCC		60 Ω		200 µW max

Note: Contact provider regarding recommended crystals for new designs.

Table 9. NDK compatible crystals (not exhaustive list)

Part number	Frequency	ESR max	C_L	Drive level (DL)
NX3225GD 8MHz EXS00A-CG04874	8 MHz	500 Ω	8 pF	200 µW max
NX3225GA 16MHz EXS00A-CG04815	16 MHz	80 Ω		
NX2016SA 16MHz EXS00A-CS07826		200 Ω		
NX3225GA 24MHz EXS00A-CG04818	24 MHz	50 Ω	8 pF	
NX2016SA 24MHz EXS00A-CS10820		80 Ω	6 pF	
NX3225GA 25MHz EXS00A-CG06750	25 MHz	50 Ω	8 pF	
NX2016SA 25MHz EXS00A-CS11321		80 Ω	6 pF	
NX2016SA32MHz EXS00A-CS10925	32 MHz	80 Ω	6 pF	
NX1612SA 40MHz EXS00A-CS13836	40 MHz	80 Ω	6 pF	100 µW max
NX1612SA 48MHz EXS00A-CS13734	48 MHz		7 pF	

6.2 Recommended ceramic resonators

Table 10 and *Table 11* give the references of recommended CERALOCK® ceramic resonators for the STM8A microcontrollers provided and certified by muRata.

Table 10. Recommended conditions (for consumer)

Part number	Frequency	C_L
CSTCR4M00G55-R0	4 MHz	$C_{L1} = C_{L2} = 39$ pF
CSTNE8M00G550000R0	8 MHz	$C_{L1} = C_{L2} = 33$ pF
CSTNE16M0V530000R0	16 MHz	$C_{L1} = C_{L2} = 15$ pF

Table 11. Recommended conditions (for CAN-BUS)

Part number	Frequency	C_L
CSTCR4M00G55B-R0	4 MHz	$C_{L1} = C_{L2} = 39$ pF
CSTNE8M00G55A000R0	8 MHz	$C_{L1} = C_{L2} = 33$ pF
CSTNE16M0V53C000R0	16 MHz	$C_{L1} = C_{L2} = 15$ pF

7 Tips for improving oscillator stability

7.1 PCB design guidelines

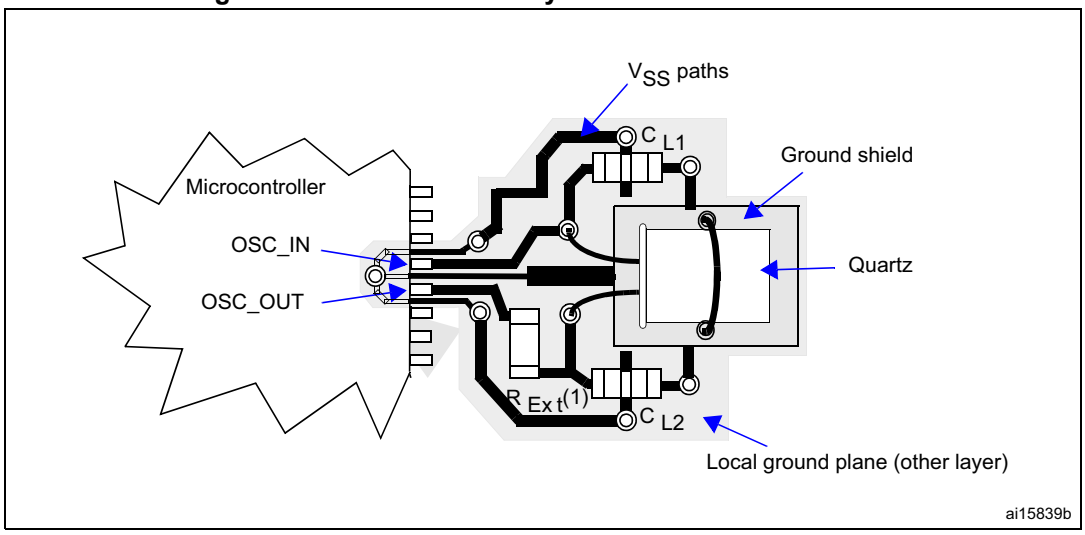
Keeping the signal-to-noise ratio (SNR) below acceptable limits for a perfect operation of the oscillator means more severe constraints on the oscillator PCB design to reduce its sensitivity to noise.

Therefore, great care must be taken when designing the PCB to reduce as much as possible the SNR. A non exhaustive list of precautions to take when designing the oscillator PCB is provided below:

- Avoid high values of stray capacitance and inductances, as they can lead to uncontrollable oscillation (the oscillator can resonate at overtones or harmonic frequencies). Reducing the stray capacitance also decreases startup time and improves oscillation frequency stability.
- To reduce high frequency noise propagation across the board, the MCU/MPU must have a stable power supply source, to ensure noiseless crystal oscillations. This means that well-sized decoupling capacitor must be used for powering the device.
- Mount the crystal as close as possible to the MCU/MPU, to keep tracks short, and to reduce inductive and capacitive effects. A guard ring around these connections, connected to the ground, is essential to avoid capturing unwanted noise, which can affect oscillation stability.

  Long tracks/paths behave as antennas for a given frequency spectrum, generating oscillation issues when passing EMI certification tests. Refer to *Figure 14* and *Figure 16*.
- Any path conveying high-frequency signals must be routed away from the oscillator paths and components. Refer to *Figure 14*.
- The oscillator PCB must be underlined with a dedicated underneath ground plane, distinct from the application PCB ground plane. The oscillator ground plane should be connected to the nearest MCU/MPU ground. It prevents interferences between the oscillator components and other application components (for example, crosstalk between paths). If a crystal in a metallic package is used, do not connect it to the oscillator ground. Refer to *Figure 13*, *Figure 14*, and *Figure 15*.
- Leakage current can increase startup time and even prevent the oscillator start. If the device operates in a severe environment (high moisture/humidity ratio), an external coating is recommended.

Figure 13. Recommended layout for an oscillator circuit



Warning: **It is highly recommended to apply conformal coatings to the PCB area shown in *Figure 13*, especially for the LSE quartz, CL1, CL2, and paths to the OSC_IN and OSC_OUT pads as a protection against moisture, dust, humidity, and temperature extremes that may lead to startup problems.**

7.2 PCB design examples

Example 1

Figure 14. PCB with separated GND plane and guard ring around the oscillator

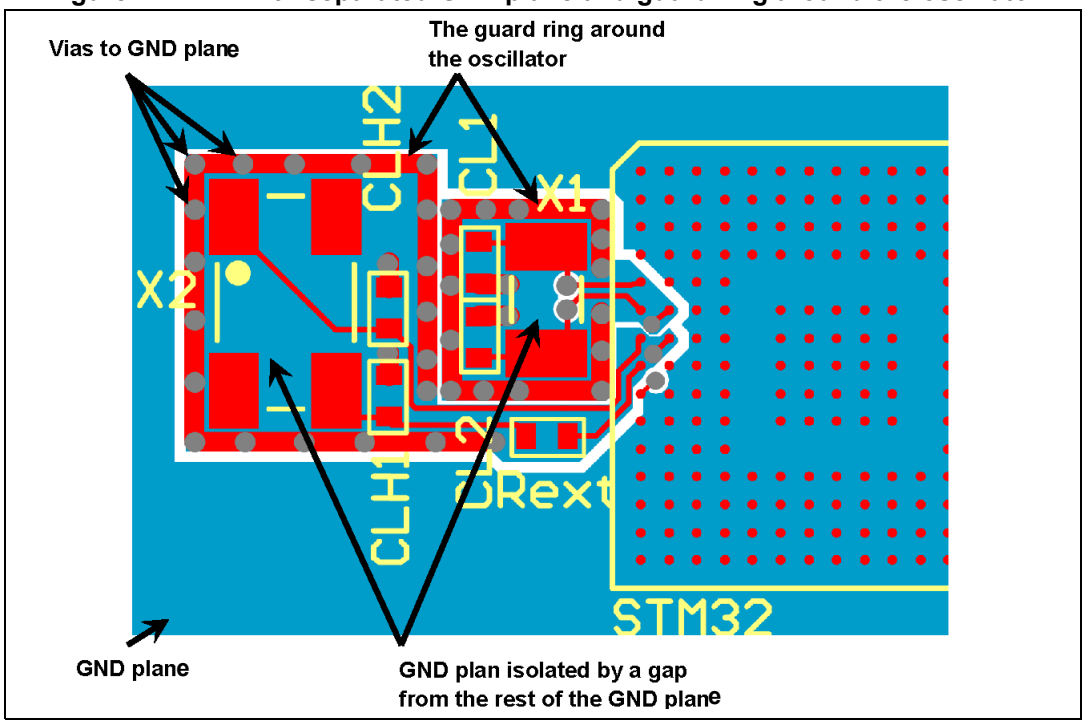


Figure 15. GND plane

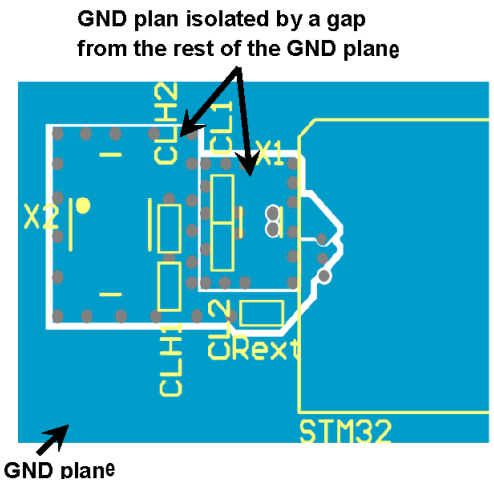
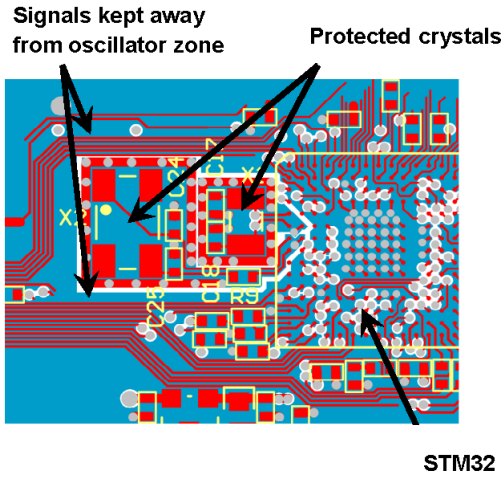


Figure 16. Signals around the oscillator

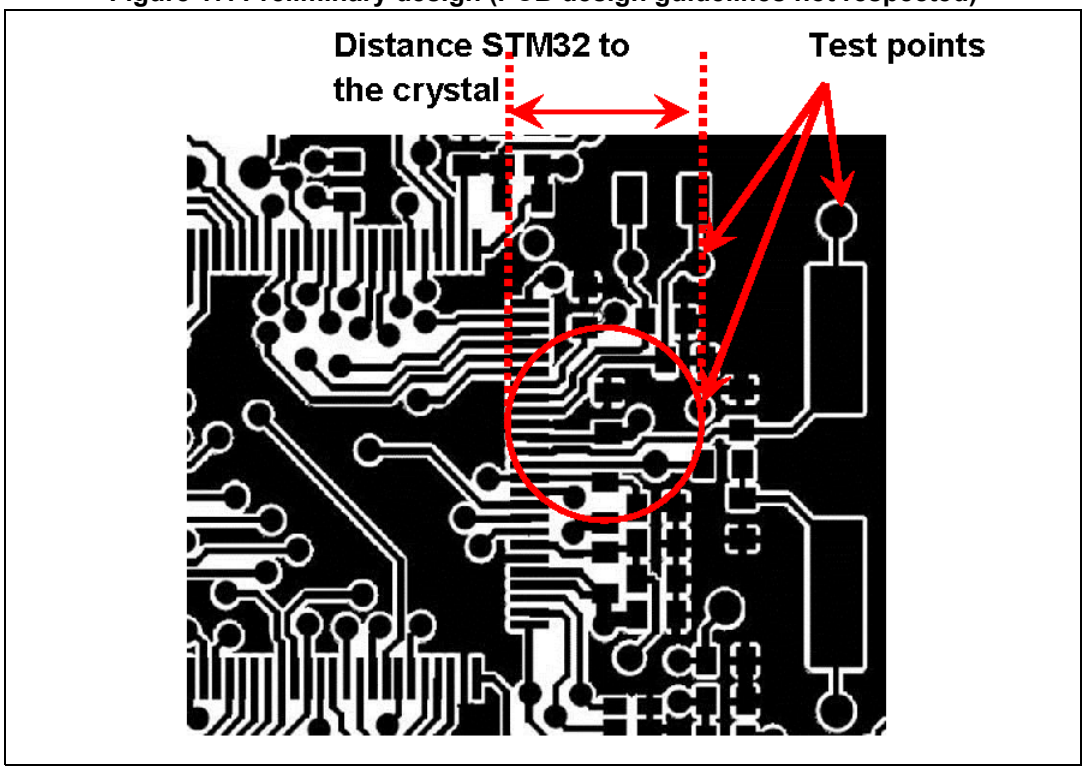


Example 2

Figure 17 is an example of a PCB that does not respect the guidelines provided in *Section 7.1*, for the following reasons:

- no ground planes around the oscillator component
- too long paths
- no symmetry between oscillator capacitances
- high crosstalk / coupling between paths
- too many test points.

Figure 17. Preliminary design (PCB design guidelines not respected)



The PCB design has been improved according to the guidelines (see *Figure 18*):

- guard ring connected to the GND plane around the oscillator
- symmetry between oscillator capacitances
- less test points
- no coupling between paths.

Figure 18. Final design (following guidelines)

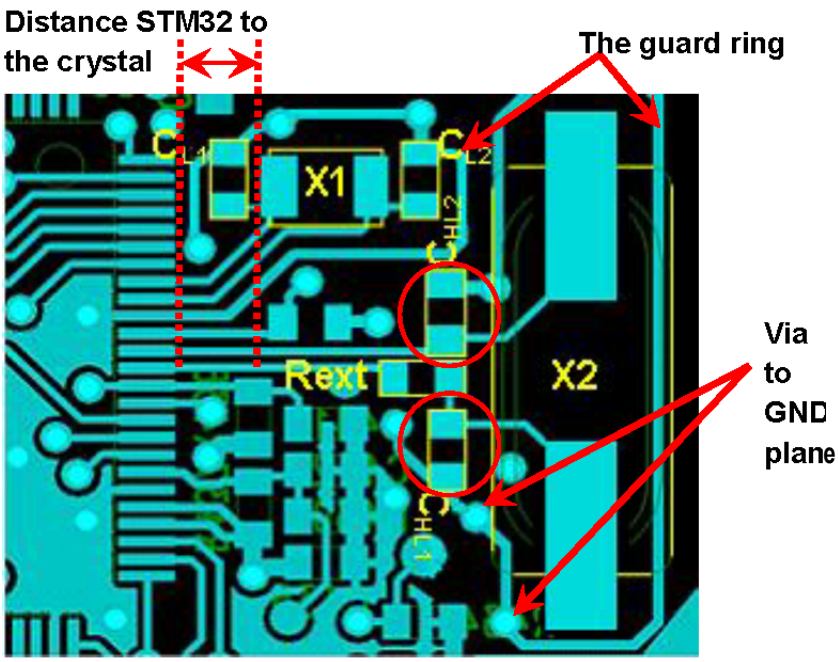


Figure 19. GND plane

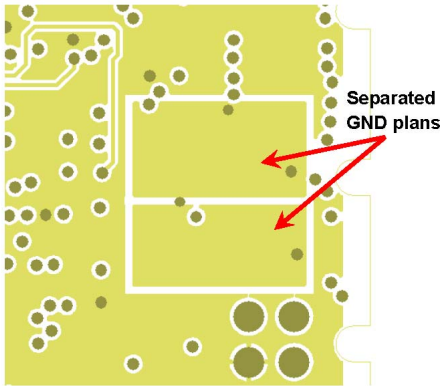
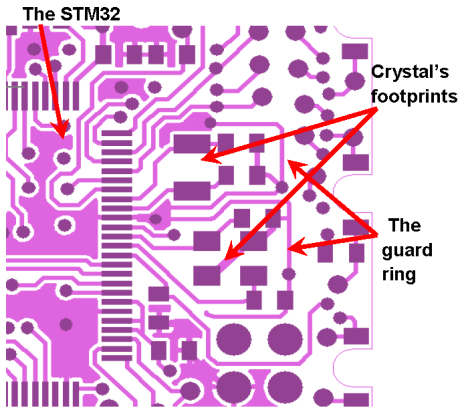


Figure 20. Top layer view

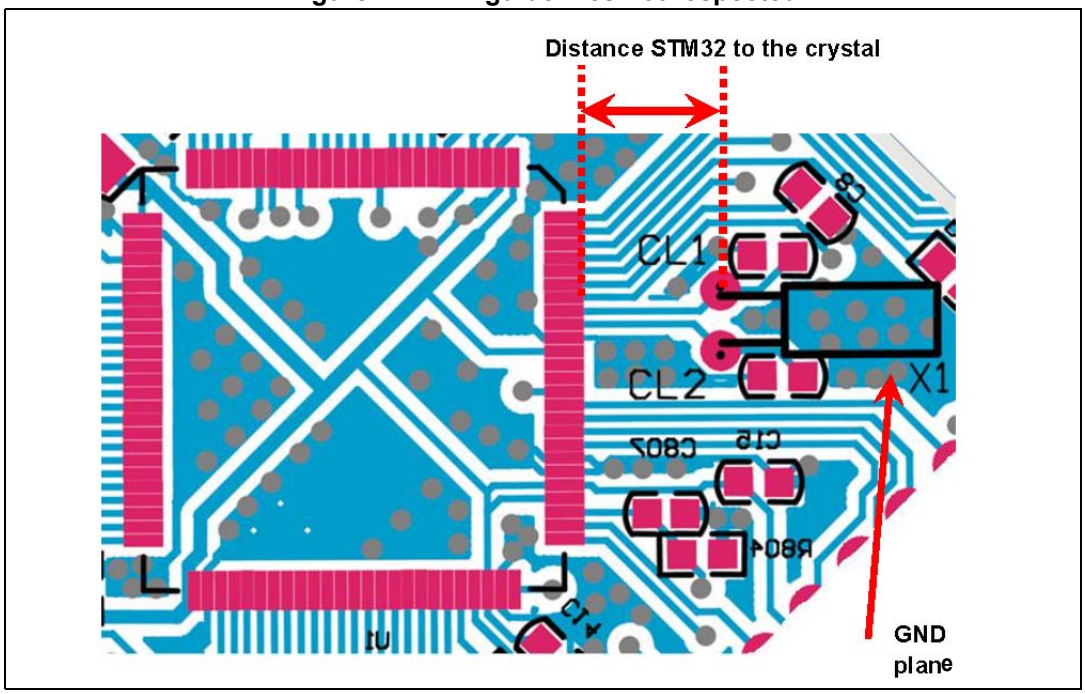


Example 3

Figure 21 is another example of PCB that does not respect the guidelines provided in *Section 7.1* (EMC tests likely to fail):

- no guard ring around oscillator components
- long paths.

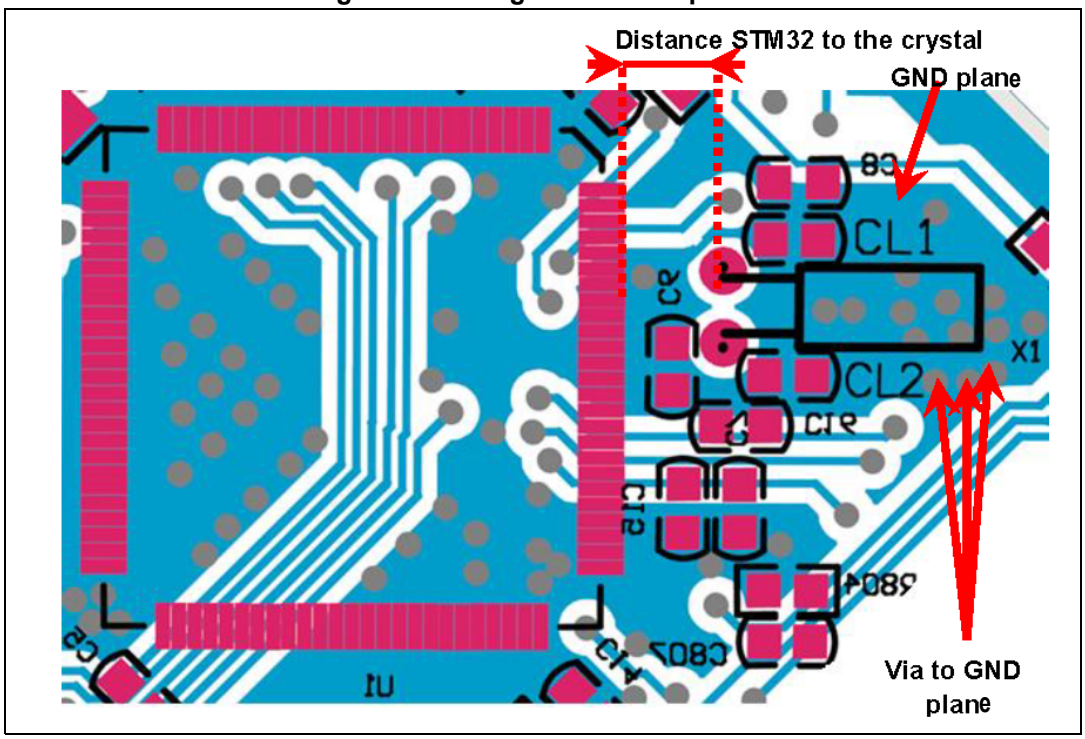
Figure 21. PCB guidelines not respected



The layout has been improved to respect the guidelines (see *Figure 22*), EMC tests are likely to be passed:

- ground planes around the oscillator component
- short paths that link the STM32 to the oscillator
- symmetry between oscillator capacitances.

Figure 22. PCB guidelines respected



7.3 Soldering guidelines

In general, soldering is a sensitive process, especially for low-frequency crystals. To reduce the impact of such process on the crystal parameters user should consider that

- Exposing crystals to temperatures above their maximum ratings can damage the crystal and affect their ESR value. Refer to the crystal datasheet for the right reflow temperature curve (if not provided, ask the manufacturer).
- PCB cleaning is recommended to obtain the maximum performance by removing flux residuals from the board after assembly (even when using “no-clean” products in ultra-low power applications).

7.4 LSE sensitivity to PC13 activity

The OSC32_IN is sensitive to PC 13 activity, When PC13 is active (toggling) the LSE clock may shift, depending upon the LSE drive configuration. For example, using PC_13 as RTC_OUT calibration for 512 Hz or 1 Hz can disturb the LSE oscillation loop, hence shift the calibration frequency.

On products having the possibility to remap RTC_OUT on another pin (for example PB2), it is recommended to use this remapping to avoid LSE disturbances.

8 Reference documents

[1] E. Vittoz *High-Performance Crystal Oscillator Circuits: Theory and Application* IEEE Journal of solid State Circuits, Vol 23, No 3, June 1988 pp 774 - 783.

9 FAQs

Question

How can I know if my crystal is compatible with a given STM32 part?

Answer

Refer to *Section 4: Guidelines to select a suitable crystal and external components*.

Question

Can I use a 32.768 kHz crystal compatible with STM32 parts but not mentioned in *Table 7*?

Answer

Yes, you can. *Table 7* is not exhaustive, it is given as a reference for some selected crystal manufacturers, footprint size, and crystal load capacitance.

Question

In my application, 32.768 kHz frequency very-low drift and high accuracy are mandatory to obtain an accurate clock without calibration. Which crystal load capacitance (C_L) should I choose?

Answer

First, you must be sure that your crystal is compatible with the selected STM32 LSE. Then, it is highly recommended to use a crystal with low pullability, that is with $C_L \geq 6$ pF:

- 7 pF is a good compromise between low drift and moderate power consumption
- 9 and 12.5 pF can be used in noisy environments, but impact the power consumption.

10 Conclusion

The most important parameter is the gain margin of the oscillator, which determines if the oscillator starts up or not. This parameter must be calculated at the beginning of the design phase, to choose a crystal suitable for the application. The second parameter is the value of the external load capacitors, to select in accordance with the C_L specification of the crystal (provided by the manufacturer). This determines the frequency accuracy. The third parameter is the value of the external resistor used to limit the drive level. In the 32 kHz oscillator part, however, it is not recommended to use an external resistor.

Because of the number of variables involved, in the experimentation phase it is recommended to select components that have exactly the same properties as those that will be used in production, and operate with the same oscillator layout and in the same environment, to avoid unexpected behavior.

Recently, MEMS oscillators have emerged on the market. They are a good alternative to resonators-based oscillators, thanks to their reduced power consumption, small size (they do not require additional passive components such as external load capacitors), and cost. This kind of oscillator is compatible with all STM32 MCUs/MPUs, except for the STM32F1 and STM32L1 series. When a MEMS oscillator is paired with an STM32 embedded oscillator, configure the latter in bypass mode.

11 Revision history

Table 12. Document revision history

Date	Revision	Changes
20-Jan-2009	1	Initial release.
10-Nov-2009	2	DL formula corrected in *Section 3.5.2: Another drive level measurement method*. Package column added to all tables in *Section 6: Some recommended crystals for STM32 microcontrollers*. Recommended part numbers updated in *Section 5.1: STM32-compatible high-speed resonators*.
27-Apr-2010	3	Added *Section 7: Some recommended crystals for STM8A/S microcontrollers*.
25-Nov-2010	4	Updated *Section 5.1: STM32-compatible high-speed resonators*: removed *Table 7: Recommendable condition (for consumer)* and *Table 8: Recommendable condition (for CAN bus)*; added *Table 8: Recommendable conditions (for consumer)*; updated Murata resonator link. Updated *Section 5.1: STM32-compatible high-speed resonators*: removed *Table 13: EPSON TOYOCOM*, *Table 14: JFVNY®*, and *Table 15: KDS*; Added *Table 6: Recommendable crystals*. Added *Warning:* after *Figure 13*.
30-Mar-2011	5	*Section 5.1: STM32-compatible high-speed resonators*: updated “STM32” with “STM8”. *Table 16: Recommendable conditions (for consumer)*: replaced ceramic resonator part number “CSTSE16M0G55A-R0” by “CSTCE16M0V53-R0”.
17-Jul-2012	6	Whole document restricted to STM32 devices.
19-Sep-2014	7	Changed STM32F1 into STM32 throughout the document. Added STM8AL series in *Table 1: Applicable products*. Replace STM8 by STM32 in *Section :* and updated hyperlink. Added *Section 7: Tips for improving oscillator stability*. Remove section *Some PCB hints*.
19-Dec-2014	8	Updated *Section 2: Oscillator theory*. Updated *Section 3: Pierce oscillator design*. Renamed section “Gain margin of the oscillator” into *Section 3.4: Oscillator transconductance* and content updated. Updated *Section 3.6: Startup time*. Updated *Section 3.7: Crystal pullability*. Updated *Section 4: Guidelines to select a suitable crystal and external components*. Updated *Section 5: Recommended resonators for STM32 MCUs/MPUs*. Added *Section 8: Reference documents*. Updated *Section 10: Conclusion*.

Table 12. Document revision history (continued)

Date	Revision	Changes
19-Feb-2015	9	Updated *Section 2.3: Negative-resistance oscillator principles* to specify the ratio between negative resistance and crystal ESR for STM8 and STM32 microcontrollers. Added *Section 3.8: Safety factor*. Added *Check the Safety Factor of the oscillation loop* step in *Section 4.2: How to select an STM32-compatible crystal*. Note moved from step 2 to 3 and updated. Renamed *Table 7: Recommended crystal / MEMS resonators for the LSE oscillator in STM32 products*.
17-Aug-2015	10	Updated *Figure 12: Classification of low-speed crystal resonators*. Added caution notes in *Section 4.1: Low-speed oscillators embedded in STM32 MCUs/MPUs*. Added STM32F7, STM32F446xx, STM32F469/479xx and STM32L4 microcontrollers in *Table 5: LSE oscillators embedded into STM32 MCUs/MPUs*. Added STM32F411xx, STM32F446xx, STM32F469/479xx and STM32L4xx microcontrollers in *Table 6: HSE oscillators embedded in STM32 MCUs/MPUs*. Updated *Table 7: Recommended crystal / MEMS resonators for the LSE oscillator in STM32 products*. Added *Section 9: FAQs*.
31-May-2017	11	Updated document title, *Introduction*, *Section 9: FAQs*, *Section 10: Conclusion*, title of *Section 6: Recommended crystals for STM8AF/AL/S MCUs*, and revision of text across the whole document. Updated *Table 5: LSE oscillators embedded into STM32 MCUs/MPUs*, *Table 6: HSE oscillators embedded in STM32 MCUs/MPUs* and *Table 7: Recommended crystal / MEMS resonators for the LSE oscillator in STM32 products*. Updated caption of *Table 8: KYOCERA compatible crystals (not exhaustive list)*, and added *Table 9: NDK compatible crystals (not exhaustive list)*. Updated *Figure 12: Classification of low-speed crystal resonators*.
21-Jan-2020	12	Updated document title, *Section 2: Oscillator theory*, *Section 5.1: STM32-compatible high-speed resonators* and *Section 5.2: STM32-compatible low-speed resonators*. Updated *Table 1: Applicable products*, *Table 5: LSE oscillators embedded into STM32 MCUs/MPUs*, *Table 6: HSE oscillators embedded in STM32 MCUs/MPUs*, *Table 7: Recommended crystal / MEMS resonators for the LSE oscillator in STM32 products*, *Table 8: KYOCERA compatible crystals (not exhaustive list)*, *Table 9: NDK compatible crystals (not exhaustive list)*, *Table 10: Recommended conditions (for consumer)* and *Table 11: Recommended conditions (for CAN-BUS)*. Minor text edits across the whole document.

Table 12. Document revision history (continued)

Date	Revision	Changes
04-Dec-2020	13	Updated *Table 7: Recommended crystal / MEMS resonators for the LSE oscillator in STM32 products* and its footnotes *2* and *3*. Updated footnotes of *Table 5: LSE oscillators embedded into STM32 MCUs/MPUs*. Added *Section 7.4: LSE sensitivity to PC13 activity*. Minor text edits across the whole document.
27-Jul-2021	14	Updated *Section 2.2: Transconductance*, *Section 3.4: Oscillator transconductance*, *Section 4.2: How to select an STM32-compatible crystal* and *Section 5.1: STM32-compatible high-speed resonators* Added *Section 3.9: Oscillation modes* and its subsections. Updated *Table 7: Recommended crystal / MEMS resonators for the LSE oscillator in STM32 products*. Minor text edits across the whole document.
05-Oct-2021	15	Added notes in *Section 3.5.2: Another drive level measurement method*, *Section 5.2: STM32-compatible low-speed resonators* and *Section 6.1: Part numbers of recommended crystal oscillators*. Added footnote *4* to *Table 5: LSE oscillators embedded into STM32 MCUs/MPUs*. Updated *Table 6: HSE oscillators embedded in STM32 MCUs/MPUs*, *Table 7: Recommended crystal / MEMS resonators for the LSE oscillator in STM32 products* and *Table 9: NDK compatible crystals (not exhaustive list)*. Minor text edits across the whole document.
22-Aug-2022	16	Updated *Table 1: Applicable products*, *Table 5: LSE oscillators embedded into STM32 MCUs/MPUs*, *Table 7: Recommended crystal / MEMS resonators for the LSE oscillator in STM32 products*, and *Table 9: NDK compatible crystals (not exhaustive list)*. Updated *Section 6.1: Part numbers of recommended crystal oscillators*. Minor text edits across the whole document.
19-Jan-2023	17	Updated *Table 5: LSE oscillators embedded into STM32 MCUs/MPUs*, *Table 6: HSE oscillators embedded in STM32 MCUs/MPUs*, and *Table 7: Recommended crystal / MEMS resonators for the LSE oscillator in STM32 products*. Minor text edits across the whole document.
25-Jan-2023	18	Updated *Table 5: LSE oscillators embedded into STM32 MCUs/MPUs*, *Table 6: HSE oscillators embedded in STM32 MCUs/MPUs*, and *Table 7: Recommended crystal / MEMS resonators for the LSE oscillator in STM32 products*. Minor text edits across the whole document.
03-Apr-2023	19	Updated *Table 5: LSE oscillators embedded into STM32 MCUs/MPUs* and *Table 7: Recommended crystal / MEMS resonators for the LSE oscillator in STM32 products*. Updated *Note:* in *Section 5.2: STM32-compatible low-speed resonators*.

Table 12. Document revision history (continued)

Date	Revision	Changes
21-Mar-2024	20	Updated document title. Updated *Table 5: LSE oscillators embedded into STM32 MCUs/MPUs*, *Table 6: HSE oscillators embedded in STM32 MCUs/MPUs*, and *Table 7: Recommended crystal / MEMS resonators for the LSE oscillator in STM32 products*. Updated footnote *a*. Updated *Section 7.1: PCB design guidelines*. Minor text edits across the whole document.
14-May-2024	21	Updated *Section 5.1: STM32-compatible high-speed resonators* and footnote *a*. Updated *Table 5: LSE oscillators embedded into STM32 MCUs/MPUs* and *Table 7: Recommended crystal / MEMS resonators for the LSE oscillator in STM32 products*. Updated *Figure 10: Quartz crystal theoretical model with third overtone.* Minor text edits across the whole document.
12-Nov-2024	22	Updated *Section 3.5.3: Calculating the external resistor*. Updated *Table 5: LSE oscillators embedded into STM32 MCUs/MPUs*, *Table 6: HSE oscillators embedded in STM32 MCUs/MPUs*, and *Table 7: Recommended crystal / MEMS resonators for the LSE oscillator in STM32 products*.
28-Jan-2025	23	Introduced STM32U3 series, hence updated *Table 5: LSE oscillators embedded into STM32 MCUs/MPUs*, *Table 6: HSE oscillators embedded in STM32 MCUs/MPUs*, and *Table 7: Recommended crystal / MEMS resonators for the LSE oscillator in STM32 products*.
02-Feb-2026	24	Introduced STM32C5 series.
13-Oct-2026	25	Introduced STM32G5 series. Introduced STM32H7P series. Updated *Table 7: Recommended crystal / MEMS resonators for the LSE oscillator in STM32 products*

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