AN2867
Application note

Oscillator design guide for STM8AF/AL/S, STM32 MCUs and MPUs

Introduction

Many designers know oscillators based on Pierce-Gate topology (hereinafter referred to as 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 product where it is embedded is already being produced). 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 being returned from the field.

This application note introduces the Pierce oscillator basics and provides guidelines for the oscillator design. It also shows how to determine the different external components, and provides guidelines for correct PCB design and for selecting suitable 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 microcontrollers*.

Table 1. Applicable products

Type	Product categories
Microcontrollers	STM8S Series, STM8AF Series and STM8AL Series
	STM32 32-bit Arm Cortex MCUs
Microprocessors	STM32 Arm Cortex MPUs

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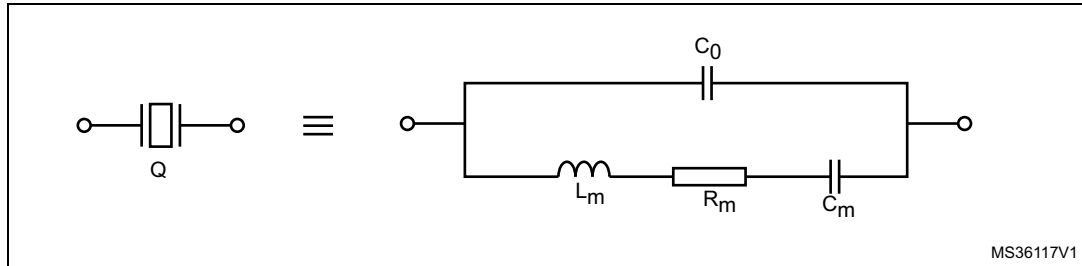
- C_0: represents the shunt capacitance resulting from the capacitor formed by the electrodes
- L_m (motional inductance): represents the vibrating mass of the crystal
- C_m (motional capacitance): represents the elasticity of the crystal
- R_m (motional resistance): represents the circuit losses

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

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

Figure 2 represents the impedance in the frequency domain.

Figure 2. Impedance in the frequency domain
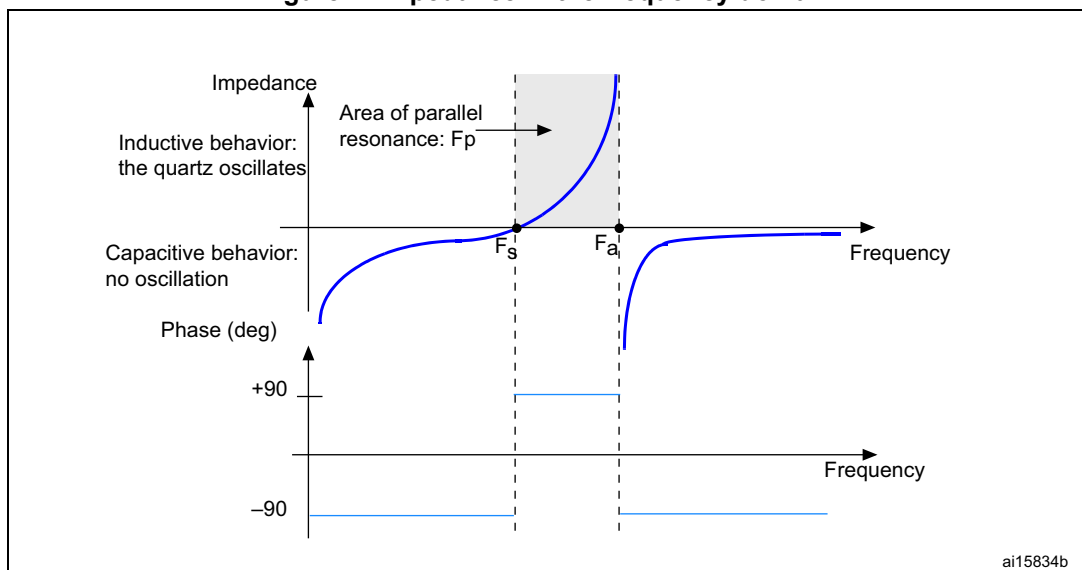
F_s is the series resonant frequency when the impedance Z = 0. Its expression can be deduced from equation *(1)* as follows:

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

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

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

The region delimited by F_s and F_a is usually called the area of parallel resonance (shaded area in *Figure 2*). 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:

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

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 to have a nominal frequency of 8 MHz.

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 determine 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 sub-families depending on their topology and operating principles. To each oscillator sub-family corresponds a suitable 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 not within the scope of this application note) with a particular focus (see *Section 3*) on Pierce-oscillator topology. This is because all the oscillators that require external passive components (external 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 sub-families:

- negative-resistance oscillators
- positive-feedback oscillators.

These two sub-families 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 some components of the oscillation loop.

These two sub-families differ in their operating principles. This difference also implies a different mathematical model to describe and analyze each sub-family.

Positive-feedback oscillators are generally 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 to analyze 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 following 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 converts the energy into an electrical current proportional to the applied voltage but flowing in the opposite direction (exactly the opposite mechanism of an electrical resistance). In the real world such a dipole does not exist.

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a. Arm is a registered trademark of Arm Limited (or its subsidiaries) in the US and/or elsewhere.

The term "negative resistance" is actually a misnomer of the "negative trans-resistance", defined by the ratio between a given voltage variation (ΔV) and the induced current variation (ΔI). Unlike the resistance, always positive, the trans-resistance (also known as differential resistance) can be either positive or negative. *Figure 3* gives the current-voltage curve for a dipole that shows a negative trans-resistance 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 trans-resistance:

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

while the portions in blue feature a positive trans-resistance:

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

Figure 3. I-V curve of a dipole showing a negative trans-resistance area (in purple)
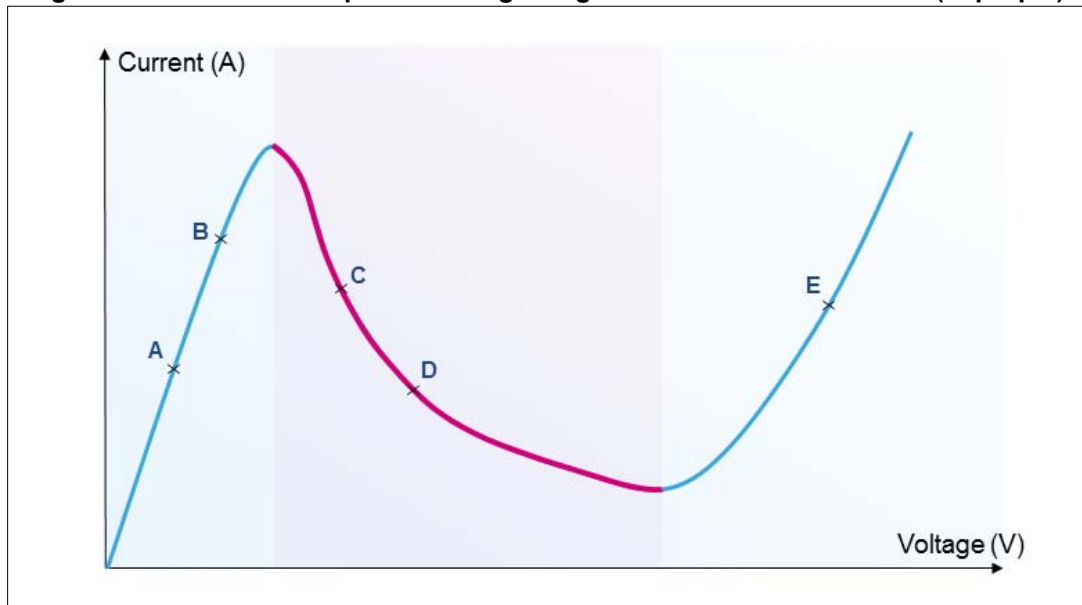
2.2 Transconductance

Similarly to the conductance, defined as the inverse of the resistance, the transconductance is defined as the inverse of the trans-resistance. 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
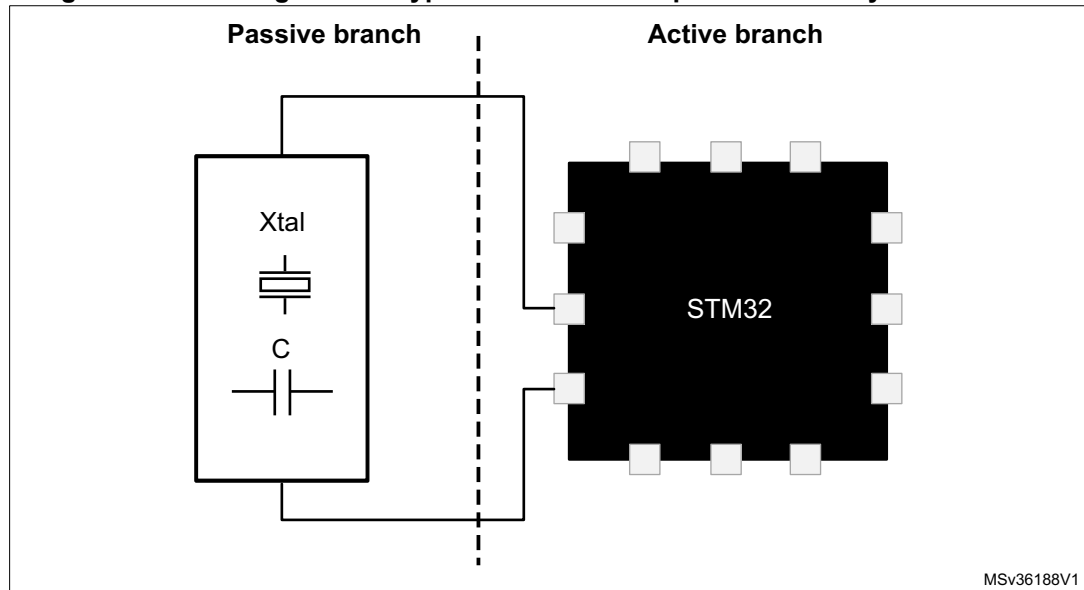
According to the small signals theory and when the active branch (oscillator part) is correctly biased, the latter must have its transconductance equal to the passive branch conductance to maintain a stable oscillation around the oscillator biasing voltage.

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 inherent noise of the oscillation loop. Note that an excessive oscillator transconductance compared to the oscillation loop passive branch conductance may also saturate the oscillation loop and cause a startup failure.

To ensure the oscillator ability to startup successfully and maintain stable oscillation, a ratio between the negative resistance of the oscillation 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 in order to be compliant with the Pierce oscillator design.

3.1   Introduction to Pierce oscillators

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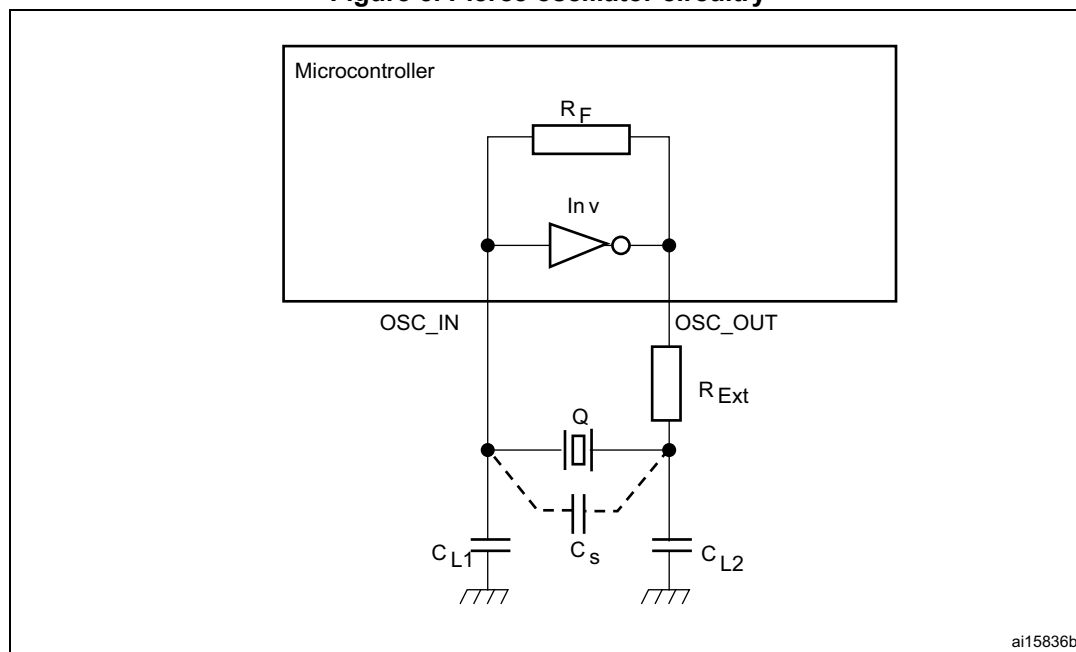
- Inv: the internal inverter that works as an amplifier
- Q: crystal quartz or a ceramic resonator
- R_F: internal feedback resistor
- R_{Ext}: external resistor to limit the inverter output current
- C_{L1} and C_{L2}: are the two external load capacitances
- C_s: stray capacitance, is the sum of the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

3.2   Feedback resistor

In most STMicroelectronics MCUs/MPUs, 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 amplifier amplifies the noise (for example, the thermal noise of the crystal) within the range of serial to parallel frequency (F_a, F_p), this noise causes the oscillation to start.

Figure 6. Inverter transfer function
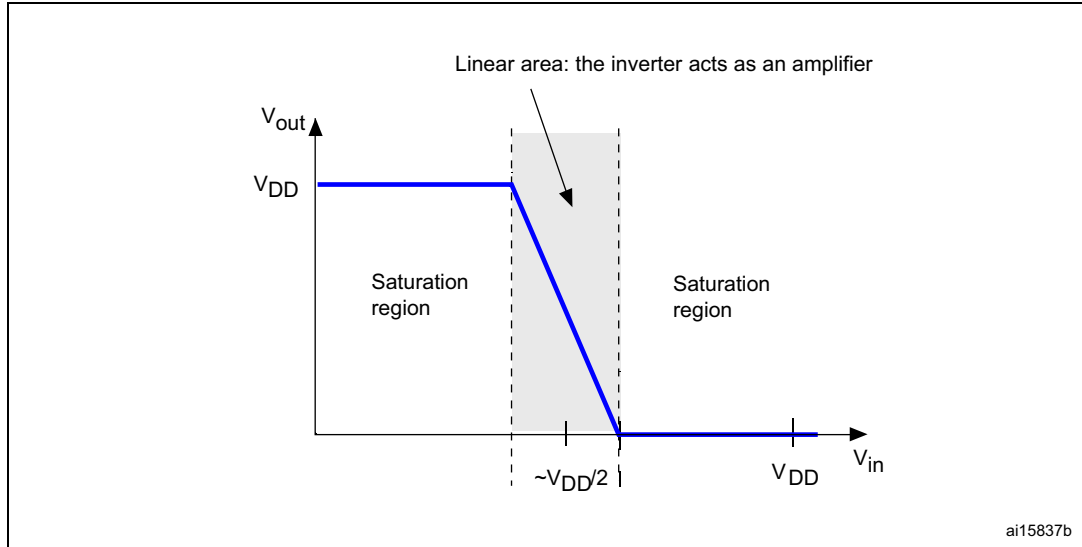
Table 3 provides typical values of R_F.

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 has to show the same load capacitance to the crystal as the one the crystal was adjusted for. Frequency stability mainly 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 oscillation loop losses and to provide the energy for the oscillation build up. When the oscillation becomes stable, the equality between the oscillator provided power and the oscillation loop dissipated power is achieved.

Practically speaking, and due to tolerances on passive component values and their dependency on environmental parameters (e.g. temperature), the ratio between oscillator gain and oscillation loop critical gain cannot just exceed 1, as this would induce a too long oscillator startup time and might 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 maximal critical crystal transconductance parameter ($G_{m\_crit\_max}$) is specified, ensure that it is greater than the oscillation loop critical 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. That the HSE oscillator transconductance is in the range of a dozen of mA/V, while LSE oscillator transconductance ranges from a few to a few dozens of µA/V, depending on the product.
* g_{mcrit} is defined as the minimal transconductance of an oscillator 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 that C_{L1} equals 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}:

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

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 reached. The oscillator is expected to reach a stable oscillation after a typical delay specified in the datasheet.

If an insufficient gain margin is found ($gain_{margin} < 5$), the oscillation might start up in some conditions (achieved in laboratory) when designing and testing the final application, but this does not guarantee that the oscillation starts up 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).

As a second example illustrating the case where the maximal critical crystal transconductance is given, the HSE oscillator embedded in an STM32G0 microcontrollers has G_m = 1.5 mA / V. g_{mcrit} operated 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 the formula $G_{m\_crit\_max} = g_m / 5$.

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 has to be limited, otherwise the quartz crystal can fail due to excessive mechanical vibration. The maximum drive level is specified by the crystal manufacturer, usually in mW. Exceeding this value may lead to the crystal being damaged, or to a shorter device lifetime.

The drive level is given by the following 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
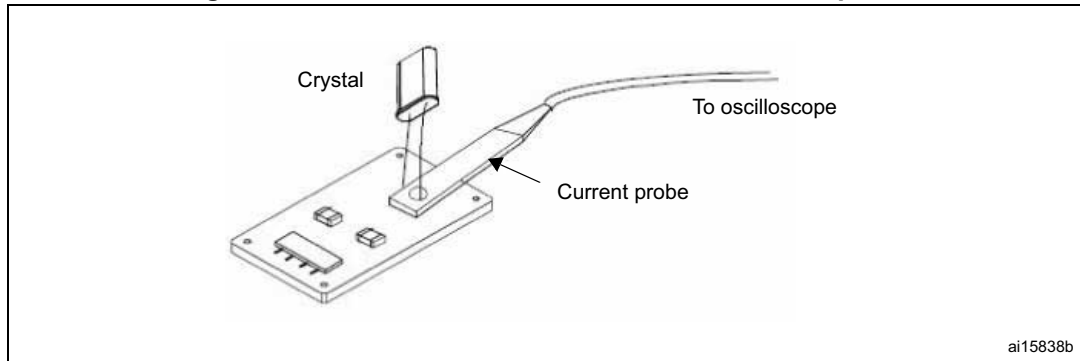
So, as described previously, when tuning the current with the potentiometer, the current through the crystal does not exceed I_{Qmax} RMS (assuming that the current through the crystal is sinusoidal).

Thus I_{Qmax} RMS is 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 current ($I_{Qmax}PP$) 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} then becomes mandatory and it 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 $DL = I^2_{QRMS} \times ESR$, where 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 $I_{QRMS} = 2\,\pi\,F \times V_{RMS} \times C_{tot}$, with:

- F = crystal frequency

- $V_{RMS} = \dfrac{V_{pp}}{2\sqrt{2}}$, 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 $DL = \dfrac{ESR \times (\pi \times F \times C_{tot})^2 \times (V_{pp})^2}{2}$.

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 0.1pF 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 of 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. That is, the value of R_{Ext} has to 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 decrease 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

The startup time is the time required by the oscillation to start up 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 then the startup time is higher if a ceramic resonator is used (ceramic resonators are know for their poor Q-factor compared to quartz-crystal resonators). The startup time also depends on the external components, C_{L1} and C_{L2}, and on the crystal frequency. The higher the crystal nominal frequency, the lower the start up time. In addition, the startup problems are usually due to the fact that 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 few ms.

The startup time of a 32.768 kHz crystal ranges from 1 to 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 usually has more importance when dealing with low-speed oscillators, since they are used to clock time-keeping functions (such as real-time clock functions).

When the final application is still in 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 due to the fact that 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 (having a ± 5% tolerance of their nominal value), C_{L1} and C_{L2}, with the same capacitances of 7 pF.

From 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 $=$ ~7.8 PPM (~0.7 s/day for a time-keeping function such as RTC)

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

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

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)

Next 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) are well known to undergo aging effects, that manifest themselves over time in a deviation of resonator parameters from their initial values defined by the specifications. Among the impacted parameters there is the resonator ESR, whose value depends on 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 the resonator 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
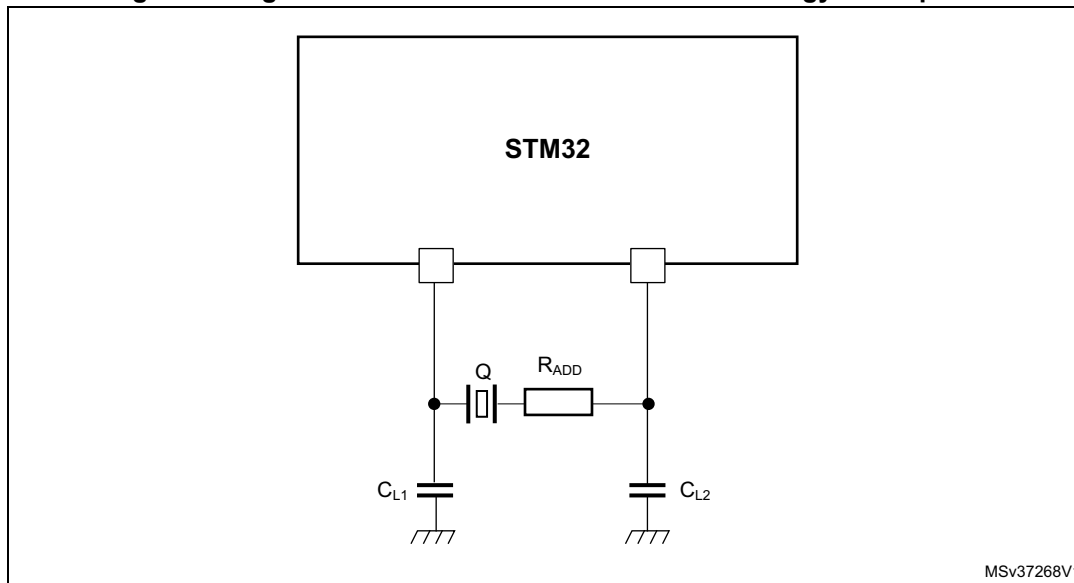
The oscillator negative resistance is the value of smallest series resistance R_{ADD} preventing the oscillator from starting up successfully.

In practice, this value is set by conducting several 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 up 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 factors for the oscillators embedded in STM32 and STM8 devices. For the LSE oscillator, the oscillation is considered safe for a safety factor higher than or equal to 3, while for the HSE oscillator this is true when the safety factor is higher than or equal to 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, while unsafe oscillation is show 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 F_p) depends 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 corresponds 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 for some spurious frequencies.

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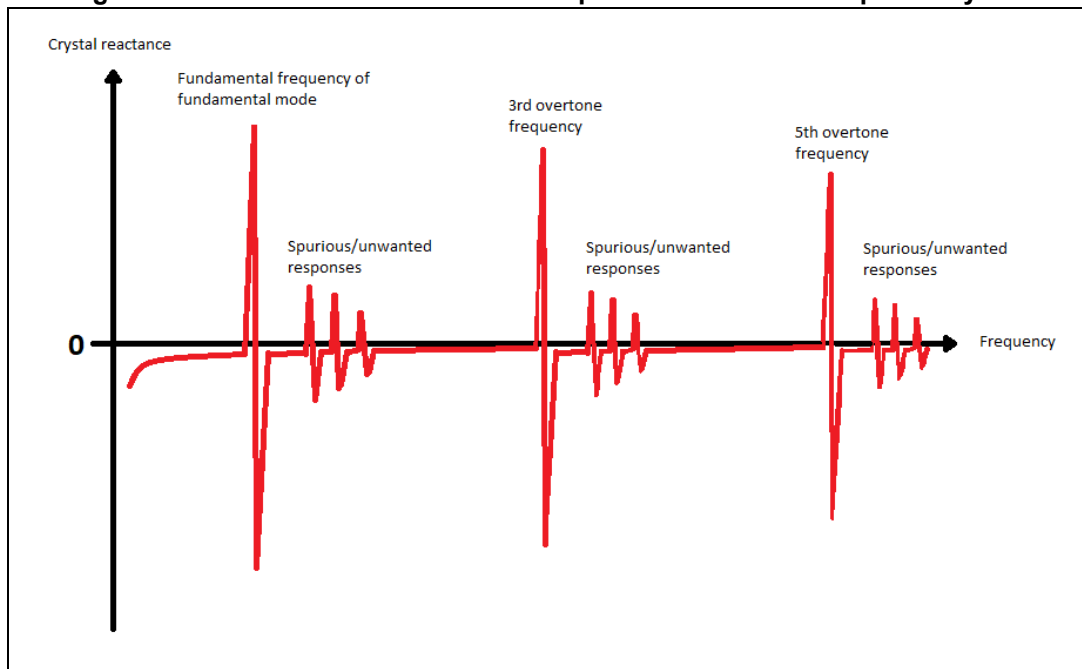
Note: *AT-cut quartz corresponds to most of the crystals to be used with HSE. For LSE, tuning fork crystals can be used but do not show the same oscillation mode possibilities (Figure 9 is not valid for such crystals). In this part, we consider an AT-cut quartz crystal when referring to a crystal.*

This multiple-time cancellation is due to the fact that a more accurate quartz crystal theoretical model shows a RLC branch for each one of its overtone modes as illustrated in *Figure 10*.

Figure 10. Quartz crystal theoretical model with third overtone
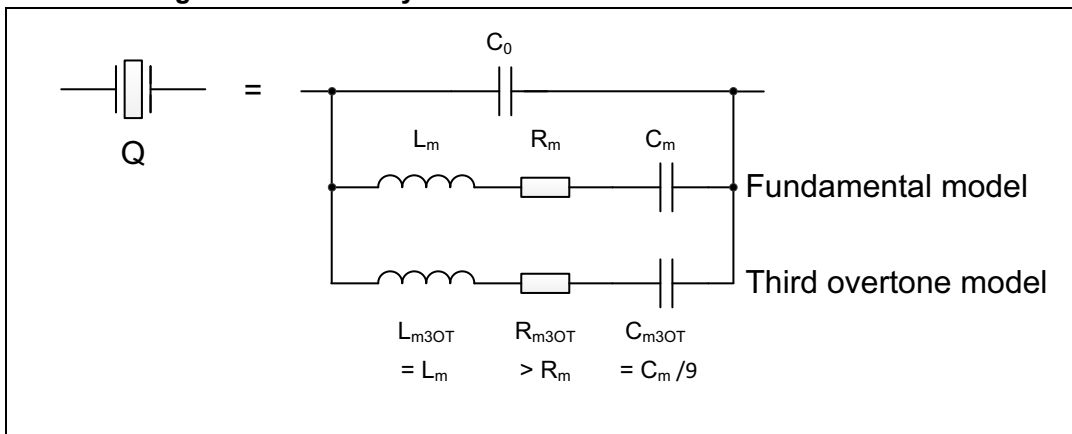
For example, it is possible to use the third overtone mode by implementing the oscillator as shown in *Figure 11*, to suppress the fundamental frequency (theoretically each overtone mode can be selected by suppressing previous ones).

Figure 11. Oscillator implementation for third overtone
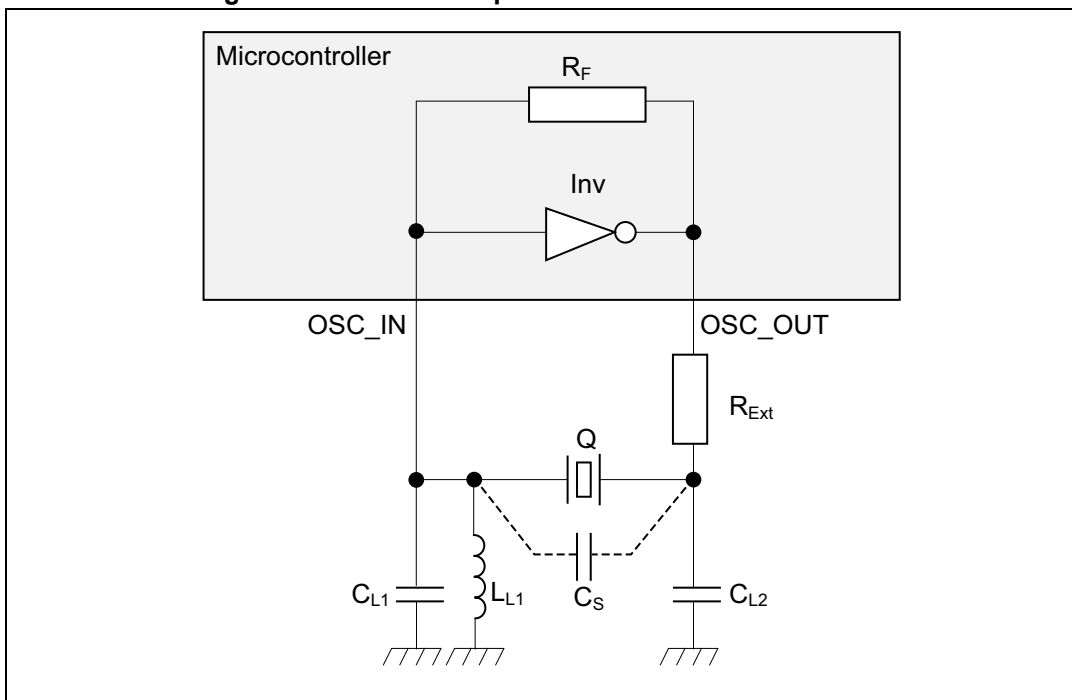
3.9.2 Third overtone mode: pros and cons

Because of the thickness needed, the crystals designed for a high frequency fundamental mode are very expensive, and require 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 three times lower frequency than the one it oscillates at).

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

For the third overtone mode, these differences mean a higher Q-factor since the quality factor for a RC series circuit is $1 / \omega RC$ (less energy loss, more stable performances, better jitter, and lower pullability (see *Section 3.7*). A lower pullability means less frequency shifting when the application is deployed in the field but also a 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. Below a list of the most important parameters that must be taken into account (only technical factors are listed):

- 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 on the above mentioned factors and trade-offs.

Figure 12. Classification of low-speed crystal resonators
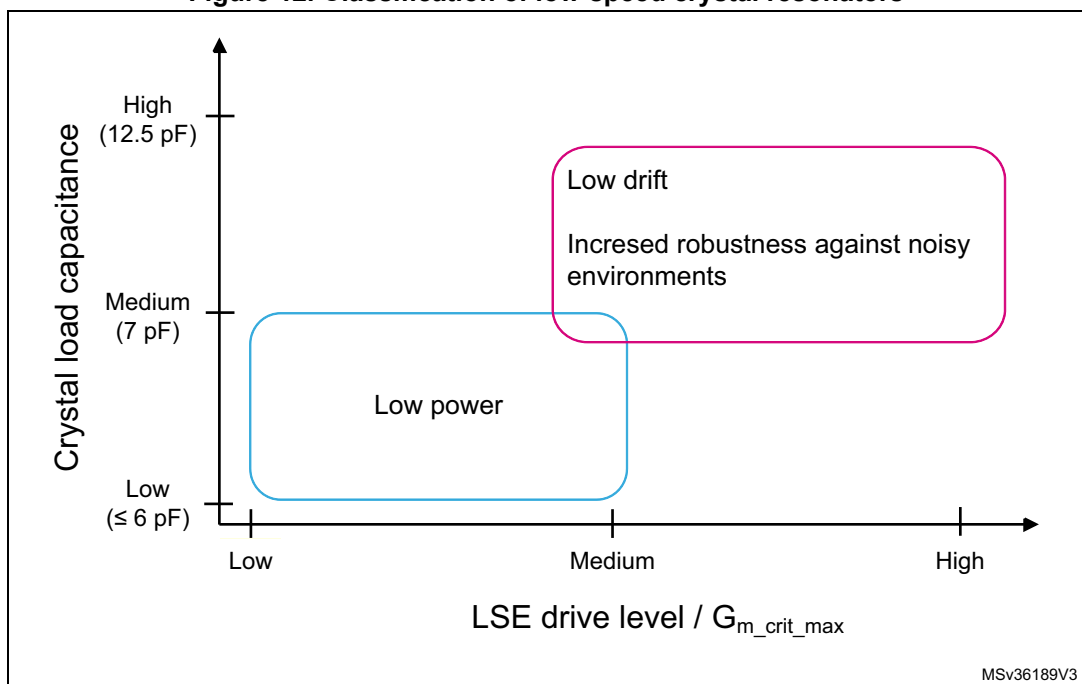
A resonator with a relatively high load-capacitance (such as 12.5 pF) requires more power for the oscillator to drive the oscillation loop at the resonator nominal frequency. Designs targeting low power consumption (e.g. RTC application powered by coin-batteries requiring very long autonomy) are consequently 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 (e.g. smart phones, Bluetooth® kits). For this market segment the crystal size is of critical importance. However it is widely known that small-footprint crystals come always with high crystal ESR. For this kind of designs, 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 environment (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 while being more robust against noise and external perturbations. Another advantage is that the design pullability is minimized.

Depending on the used device, 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 low-speed oscillators

    This type of LSE oscillators 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 microcontrollers target designs with severe power consumption constraint. The selected crystal should consequently have a low load capacitance and a moderate ESR. LSE oscillators embedded into STM32F1 microcontrollers target crystal resonators with moderate ESR and moderate load capacitance.

*   Configurable-gain low-speed oscillators

    LSE oscillators belonging to this family have the main advantage to be compatible with a large number of crystals. Almost no constraint is by the STM32 device embedding this kind of LSE oscillator. This large list of compatible resonator crystals allows to focus only on design constraints (e.g. power consumption, footprint) when selecting a compatible resonator. These LSE 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 either statically or on-the-fly, the calibration of the oscillation frequency must be re-adjusted to estimate the final accuracy uncertainty (PPM) budget.

Caution: In STM32F0 and STM32F3 MCUs, High drive mode (g_m = 25 µA/V) should 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 (e.g. C_L = 6 pF), the oscillation frequency jitters and duty cycle may be distorted.

Table 5. LSE oscillators embedded into STM32 MCUs/MPUs[1]

Drive level	F0 Series / F3 Series				F1 Series T Series	F2 Series	F4_g1[2]	F4_g2[3]		F7 Series				L1 Series	L0 Series / L4 Series L4+ Series / L5 Series G0 Series / G4 Series H7 Series / WB Series MP1 Series / U5 Series[4]				Unit
	Low	Medium Low	Medium High	High	NA	NA	NA	Low	High	Low	Medium Low	Medium High	High	NA	Low	Medium Low	Medium High	High	
$g_{m\,(min)}$	5	8	15	25	5	2.8	2.8	2.8	7.5	2.4	3.75	8.5	13.5	3	2.5	3.75	8.5	13.5	µA/V
$G_{m\_crit\_max}$	1	1.6	3	5	1	0.56	0.56	0.56	1.5	0.48	0.75	1.7	2.7	0.6	0.5	0.75	1.7	2.7	

1. Color code:
   Yellow: LSE oscillators with transconductance modifiable on the fly (dynamically).
   Green: LSE oscillators with non-modifiable transconductance.
   Gray: LSE oscillators with statically-modifiable transconductance.

2. F4_g1: STM32F4 Series with LSE generation 1. This category 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. This category corresponds to STM32F410/411/412/413/423/446/469/479xx MCUs featuring LSE oscillators with statically-modifiable transconductance.

4. STM32U5 Series does 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 whole procedure is divided into 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 which procedure has to be followed 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 the second procedure should be applied. 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 g_{mcrit} 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 right capacitance values for C_{L1} and C_{L2} load capacitors, apply the formula specified in *Section 3.3: Load capacitance*. 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, a series of experimental iterations should be performed until the right capacitance values are found.

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

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

where:

- F_{etalon} is the etalon crystal oscillation frequency when the crystal is loaded by its nominal load capacitance.

- $F_{nominal}$ is the oscillation nominal frequency specified in the crystal datasheet.

- PPM_{etalon} is the oscillation frequency drift of the etalon crystal as it characterized by the crystal manufacturer.

When F_{etalon} is computed, go through the sequence below:

1. The first experimental iteration should be made with C_{L1} and C_{L2} capacitance values determined by calculation:
   – If the oscillation frequency is equal to F_{etalon}, then C_{L1} and C_{L2} are the correct capacitances. User can therefore skip sub-steps 2 and 3.
   – If the oscillation frequency is slower than F_{etalon} then go to sub-step 2.
   – Otherwise execute sub-step 3.

2. For this experimental iteration, decrease C_{L1} and C_{L2} capacitance values, measure again the oscillation frequency and compare it to F_{etalon}:
   – If the oscillation frequency is slower than F_{etalon}, execute sub-step 2.
   – Otherwise execute sub-step 3.
   – If the oscillation frequency is almost equal to F_{etalon} then 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_{etalon}:
   – If the oscillation frequency is slower than F_{etalon} then execute sub-step 2.
   – Otherwise execute sub-step 3.
   – If the oscillation frequency is almost equal to F_{etalon} then the latter C_{L1} and C_{L2} capacitance values should be used.

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 microcontroller / 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 $DL > DL_{crystal}$, user should calculate R_{Ext} in order to have: $DL < DL_{crystal}$. 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

Finally, use the formula below 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: Crystal pullability*).

Note: *The PPM budget calculated above does not take into account the temperature variation that may 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 microcontrollers[a] is compatible with almost all the resonators available on the market. They are provided by a wide range of manufacturers, including:

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

Compatible resonators have 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	STM32F0 STM32F3	STM32F1 STM32T	STM32F2	STM32F4	STM32F7	STM32L0	STM32L1	STM32L4 STM32L4+ STM32L5 STM32H7 STM32G0 STM32G4 STM32MP1	STM32U5	Unit
Frequency range	4 - 32	4 - 16	4 - 25	4 - 26	4 - 26	1 - 25	1 - 24	4 - 48	4 - 50	MHz
$g_{m\,(min)}$	10	25	5	5	5	3.5	3.5	7.5	7.5	mA/V
$G_{m\_crit\_max}$	2	5	1	1	1	0.7	0.7	1.5	1.5	

5.2 STM32-compatible low-speed resonators

Table 7 contains a not exhaustive set (only the compatible resonator part-numbers checked by STMicroelectronics are listed) of low-speed quartz-crystal 32.768 kHz resonators that are either compatible with the whole STM32 portfolio or with a subset. Different footprints are provided to facilitate crystal selection even if there are geometric constraints for the final application.

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a. This is not applicable for STM32WB and STM32WL Series due to the RF constraints. For information about HSE oscillator compatibility with STM32WB and STM32WLSeries, refer to *Precise HSE frequency and startup time tuning for STM32 wireless MCUs* (AN5042) available on *www.st.com*.

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

Package size	Manufacturer	Quartz ref / Part number	ESR max (kΩ)	C_0 (pF)	C_L (pF)	g_{mcrit}[1] (µA/V)	STM32 Series compatibility[2][3]
0.95x0.6 mm	muRata	WMRAG32K76CS1C00R0	75	0.003	8	0.8144	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		WMRAG32K76CS2C00R0					F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		WMRAG32K76CS3C00R0					F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		WMRAG32K76CS4C00R0					F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		WMRAG32K76CT2C00R0			9	1.0308	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		WMRAG32K76CV2C00R0			12.5	1.9880	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
1.2x1.0 mm	RIVER	TFX-05X	90	1.5	5	0.6447	F0, F1, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, H7, WB, WL, MP1
					7	1.1026	F0, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, H7, WB, WL, MP1, U5
					9	1.6824	F0, F3, L0, L4, L4+, L5, G0, G4, F7, H7, WB, WL, MP1, U5
					12.5	2.9910	F0, F3
	SII	SC-12S (2 terminals)	90	1.4	6	0.8356	F0, F1, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, H7, WB, WL, MP1
					7	1.0768	F0, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, H7, WB, WL, MP1, U5
					9	1.6506	F0, F3, L0, L4, L4+, L5, G0, G4, F7, H7, WB, WL, MP1, U5
					12.5	2.9484	F0, F3
	ECS	ECS-.327-7-1210-TR	90	1.1	7	1.0012	F0, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-9-1210-TR			9	1.5567	F0, F3, L0, L4, L4+, L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-12.5-1210-TR			12.5	2.8225	F0, F3
		ECS-.327-5-1210B-CN-TR	80	1.5	5	0.5731	F0, F1, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, H7, WB, WL, MP1
		ECS-.327-7-1210B-CN-TR			7	0.9800	F0, F1, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-9-1210B-CN-TR			9	1.4955	F0, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-12.5-1210B-CN-TR			12.5	2.6587	F0, F3, L0, L4, L4+, L5, G0, G4, F7, H7, WB, WL, MP1, U5
	ABRACON	ABS04W-32.768 KHz 4 pF	80	1.5	4	0.4103	F0, F1, F2, F3, F4, L0, L1, L4, L4+, L5, G0, G4, F7, H7, WB, WL, MP1
		ABS04W-32.768 KHz 6 pF			6	0.7630	F0, F1, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, H7, WB, WL, MP1
		ABS04W-32.768 KHz 9 pF			9	1.4955	F0, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ABS04W-32.768 KHz 12.5 pF			12.5	2.6587	F0, F3, L0, L4, L4+, L5, G0, G4, F7, H7, WB, WL, MP1, U5

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

Package size	Manufacturer	Quartz ref / Part number	ESR max (kΩ)	C_0 (pF)	C_L (pF)	g_{mcrit}[1] (µA/V)	STM32 Series compatibility[2][3]
1.6x1.0 mm	Micro Crystal	CM9V-T1A / CM9V-T1A 0.3	90	1.4	4	0.4449	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					6	0.8356	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					7	1.0768	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					9	1.6506	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					12.5	2.9484	F0, F3
	ECS	ECS-.327-6.5-16-TR		1.3	6.5	0.9284	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ECS-.327-9-16-TR			9	1.6190	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, 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	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					9	1.6190	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					12.5	2.9062	F0, F3
		NX1610SE STD-MUD-6	60	1.55	6	0.5799	F0, F1, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, H7, WB, WL, MP1
		NX1610SE STD-MUD-5			9	1.1323	F0, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, H7, WB, WL, MP1, U5
		NX1610SE STD-MUD-4			12.5	2.0083	F0, F3, L0, L4, L4+, L5, G0, G4, F7, H7, WB, WL, MP1, U5
	SII	SC-16S		1.2	6	0.7910	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					12.5	2.8642	F0, F3
	EPSON	FC1610AN 32.768000 kHz 9	90	1.2	9	1.5877	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		FC1610AN 32.768000 kHz 12.5			12.5	2.8642	F0, F3
	CITIZEN	CM1610H		1.2	6	0.7910	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					7	1.0261	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					9	1.5877	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					12.5	2.8642	F0, F3
	ABRACON	ABS05-32.768 kHz 9 pF	90	1.3	9	1.6190	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ABS05-32.768 kHz			12.5	2.9062	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ABS05W-32.768 kHz-D	70	2	4	0.4272	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1

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

Package size	Manufacturer	Quartz ref / Part number	ESR max (kΩ)	C_0 (pF)	C_L (pF)	g_{mcrit}[1] (µA/V)	STM32 Series compatibility[2][3]
1.6x1.0 mm	RIVER	TFX-04	90	1.3	5	0.6056	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					7	1.0513	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					9	1.6190	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					12.5	2.9062	F0, F3
		TFX-04C	60	1.5	5	0.4298	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					7	0.7350	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					9	1.1216	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					12.5	1.9940	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
2.0x1.2 mm	ABRACON	ABS06L-32.768kHz-9pF	100	-	9	1.3734	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ABS06L-32.768kHz			12.5	2.6494	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ABS06W-32.768kHz-D	95	1	3	0.2577	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ABS06-127-32.768kHz	90	-	12.5	2.3844	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ABS06-32.768kHz-4P			4	0.2441	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ABS06-32.768kHz-6			6	0.5493	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ABS06-32.768kHz-7			7	0.7477	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ABS06-32.768kHz-9			9	1.2361	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ABS06-32.768kHz			12.5	2.3844	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ABS06-107-32.768kHz-T	80	1.5	4	0.4103	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
	ECS	ECS-.327-6-12L-TR	100	1.3	6	0.9035	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ECS-.327-7-12L-TR			7	1.1681	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-9-12L-TR			9	1.7988	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-12.5-12L-TR			12.5	3.2299	F0, F3

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

Package size	Manufacturer	Quartz ref / Part number	ESR max (kΩ)	C_0 (pF)	C_L (pF)	g_{mcrit}[1] (µA/V)	STM32 Series compatibility[2][3]
2.0x1.2 mm	ECS	ECS-.327-6-12L-TR	100	1.3	6	0.9035	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ECS-.327-7-12L-TR			7	1.1681	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-9-12L-TR			9	1.7988	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-12.5-12L-TR			12.5	3.2299	F0, F3
		ECS-.327-6-12-TR	90		6	0.8312	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ECS-.327-7-12-TR			7	1.0513	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-9-12-TR			9	1.6190	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-12.5-12-TR			12.5	2.9062	F0, F3
		ECS-.327-CDX-1082	80	1.5	4	0.4103	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ECS-.327-6-12RR-TR	70	1.7	6	0.7372	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ECS-.327-7-12RR-TR			7	0.8983	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-9-12RR-TR			9	1.3589	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-12.5-12R-TR			12.5	2.3933	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-6-12R-TR		1.3	6	0.4517	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ECS-.327-9-12R-TR			9	0.8994	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-12.5-12R-TR			12.5	1.6145	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5

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

Package size	Manufacturer	Quartz ref / Part number	ESR max (kΩ)	C_0 (pF)	C_L (pF)	g_{mcrit}[1] (µA/V)	STM32 Series compatibility[2][3]
2.0x1.2 mm	Micro Crystal	CM8V-T1A 0.3	90		4	0.4126	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					6	0.7910	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					7	1.0261	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					9	1.5877	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					12.5	2.8642	F0, F3
		CC8V-T1A	80	1.2	4	0.3667	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					6	0.7031	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					7	0.9120	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					9	1.4113	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					12.5	2.5460	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		CM8V-T1A	70		4	0.3209	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					6	0.6152	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					7	0.7980	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					9	1.2349	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					12.5	2.2277	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, 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	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		FC-12D 32.768000kHz 9			9	1.2213	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		FC-12D 32.768000kHz 12.5			12.5	2.2495	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
	RIVER	TFX-03	90	1.3	5	0.6447	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					7	1.0513	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					9	1.6190	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					12.5	2.9062	F0, F3
		TFX-03C	60	1.8	5	0.4704	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					7	0.7878	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					9	1.1866	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					12.5	2.0804	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5

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

Package size	Manufacturer	Quartz ref / Part number	ESR max (kΩ)	C_0 (pF)	C_L (pF)	g_{mcrit}[1] (μA/V)	STM32 Series compatibility[2][3]
2.0x1.2 mm	KYOCERA	ST2012SB 32768 Z0	80	1.3	4	0.3810	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ST2012SB 32768 A0			5	0.5383	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ST2012SB 32768 B0			6	0.7228	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ST2012SB 32768 C0			7	0.9344	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ST2012SB 32768 E0			9	1.4391	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ST2012SB 32768 H5			12.5	2.5833	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
	NDK	NX2012SA 32.768 kHz EXS00A-MU00137			6	0.7228	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					9	1.4391	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					12.5	2.5833	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		NX2012SE STD-MUB-8	50	1.7	6	0.5026	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		NX2012SE STD-MUB-9			9	0.9706	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		NX2012SE STD-MUB-10			12.5	1.7095	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
	SII	SC-20T	75	1	6	0.6231	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					7	0.8138	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					9	1.2717	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					12.5	2.3177	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		SC-20S	70	1.3	6	0.6325	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					12.5	2.2604	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
	CITIZEN	CM2012H			6	0.6325	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					7	0.8176	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					9	1.2592	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					12.5	2.2604	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5

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

Package size	Manufacturer	Quartz ref / Part number	ESR max (kΩ)	C_0 (pF)	C_L (pF)	g_{mcrit}[1] (µA/V)	STM32 Series compatibility[2][3]
3.2x1.5 mm	KYOCERA	ST3215SB 32768 Z0	70	0.9	4	0.2849	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ST3215SB 32768 A0			5	0.4131	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ST3215SB 32768 B0			6	0.5650	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ST3215SB 32768 C0			7	0.7407	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ST3215SB 32768 E0			9	1.1633	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ST3215SB 32768 H5			12.5	2.1312	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
	ABRACON	ABS07L-32.768kHz 7pF	80	1.4	7	0.9751	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ABS07L-32.768kHz 9pF			9	1.6472	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ABS07L-32.768kHz			12.5	2.6208	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ABS07-32.768kHz 6pF	70	11	6	0.5815	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ABS07-32.768kHz 7pF			7	0.7596	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ABS07-32.768kHz 9pF			9	1.1869	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ABS07 32.768kHz			12.5	2.1631	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ABS07-166-32.768kHz-T			7	0.7596	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ABS07-120-32.768kHz-T	60	1.2	6	0.5273	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ABS07W-32.768kHz-D	55	1.15	3	0.1606	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ABS07-LR-32.768 kHz-6	50	1.3	6	0.4517	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1

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

Package size	Manufacturer	Quartz ref / Part number	ESR max (kΩ)	C_0 (pF)	C_L (pF)	g_{mcrit}[1] (µA/V)	STM32 Series compatibility[2][3]
3.2x1.5 mm	CITIZEN	CM315D	70	0,95	6	0.5733	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					7	0.7501	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					9	1.1751	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					12.5	2.1471	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		CM315E	70	0,75	4	0.2678	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					6	0.5407	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					8	0.9087	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					9	1.1283	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					12.5	2.0838	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		CM315DL	50	1,3	6	0.4517	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					7	0.5840	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					9	0.8994	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					12.5	1.6145	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
	Micro Crystal	CC7V-T1A CM7V-T1A (low profile)	70	1,2	6	0.6152	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					7	0.7980	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					9	1.2349	F0, F3, F4_g2, L0, L4, L4+, L5, G0, G4, F7, H7, WB, WL, MP1, U5
					12.5	2.2277	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		CM7V-T1A 0.3	60	1,4	6	0.5571	F0, F1, F2, F3, F4, L0, L1, L4, L5, G0, G4, F7, H7, WB, WL, MP1
					7	0.7178	F0, F1, F3, F4_g2, L0, L4, L5, G0, G4, F7, H7, WB, WL, MP1, U5
					9	1.1004	F0, F3, F4_g2, L0, L4, L5, G0, G4, F7, H7, WB, WL, MP1, U5
					12.5	1.9656	F0, F3, L0, L4, L5, G0, G4, F7, H7, WB, WL, MP1, U5, U5
		CM7V-T1A	50	1,3	6	0.4517	F0, F1, F2, F3, F4, L0, L1,L4, L5, G0, G4, F7, H7, WB, WL, MP1
					7	0.5840	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					9	0.8994	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					12.5	1.6145	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5

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

Package size	Manufacturer	Quartz ref / Part number	ESR max (kΩ)	C_0 (pF)	C_L (pF)	g_{mcrit}[1] (µA/V)	STM32 Series compatibility[2][3]
3.2x1.5 mm	EPSON	FC-135 32.768000 kHz 7	70	1	7	0.7596	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		FC-135 32.768000 kHz 9			9	1.1869	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		FC-135 32.768000 kHz 12.5			12.5	2.1631	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		FC-13A 32.768000 kHz 9		0.9	9	1.1633	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		FC-13A 32.768000 kHz 12.5			12.5	2.1312	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		FC-135R 32.768000 kHz 7	50	1.1	7	0.5562	F0, F1, F3, F4_g2, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		FC-135R 32.768000 kHz 9			9	0.8648	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		FC-135R 32.768000 kHz 12.5			12.5	1.5681	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
	SII	SC-32S	70	1	6	0,5815	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					12.5	2.1631	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		SC-32P	50		6	0,4154	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					12.5	1.5451	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5

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

Package size	Manufacturer	Quartz ref / Part number	ESR max (kΩ)	C_0 (pF)	C_L (pF)	g_{mcrit}[1] (µA/V)	STM32 Series compatibility[2][3]
3.2x1.5 mm	ECS	ECS-.327-6-34QS-TR	70	1,1	6	0.5983	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ECS-.327-7-34QS-TR			7	0.7787	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-9-34QS-TR			9	1.2108	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-12.5-34QS-TR			12.5	2.1953	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-6-34G-TR		0,75	6	0.5407	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ECS-.327-12.5-34G-TR			12.5	2.0838	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-6-34S-TR		1,05	6	0.5899	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ECS-.327-12.5-34S-TR			12.5	2.1792	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECX-.327-CDX-1293			12.5	2.1792	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-7-34B-TR			7	0.7691	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-9-34B-TR			9	1.1988	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-12.5-34B-TR			12.5	2.1792	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-CDX-1128	60	2	6	0.6511	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ECS-.327-6-34R-TR	50	1,3	6	0.4517	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ECS-.327-7-34R-TR			7	0.5840	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-9-34R-TR			9	0.8994	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-12.5-34R-TR			12.5	1.6145	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-6-34RR-TR	40		6	0.3614	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ECS-.327-9-34RR-TR			9	0.7195	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-12.5-34RR-TR			12.5	1.2916	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
	NDK	NX3215SE STD-MUA-19	40	1.3	6	0.3614	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		NX3215SE STD-MUA-18			9	0.7195	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		NX3215SE STD-MUA-17			12.5	1.2916	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5

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

Package size	Manufacturer	Quartz ref / Part number	ESR max (kΩ)	C_0 (pF)	C_L (pF)	g_{mcrit}[1] (μA/V)	STM32 Series compatibility[2][3]
4.1x1.5 mm	Micro Crystal	CC5V-T1A	70	1.2	6	0.6152	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					7	0.7980	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					9	1.2349	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					12.5	2.2277	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
	ECS	ECS-.327-6-49-TR		1.1	6	0.5983	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ECS-.327-7-49-TR			7	0.7787	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-9-49-TR			9	1.2108	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-12.5-49-TR			12.5	2.1953	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
4.9x1.8 mm	CITIZEN	CM519		1.35	6	0.6412	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					7	0.8274	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					9	1.2714	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					12.5	2.2768	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
	ECS	ECS-.327-6-39-TR		1.33	6	0.6377	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ECS-.327-7-39-TR			7	0.8235	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-9-39-TR			9	1.2665	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-12.5-39-TR			12.5	2.2702	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
6.9 x 1.4 mm	ABRACON	ABS13 -32.768kHz-7pF	65	-	7	0.5400	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ABS13 -32.768kHz			12.5	1.7221	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5

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

Package size	Manufacturer	Quartz ref / Part number	ESR max (kΩ)	C_0 (pF)	C_L (pF)	g_{mcrit}[1] (µA/V)	STM32 Series compatibility[2][3]
7.0 x 1.5 mm	SII	SSP-T7-F	65	0.9	7	0.6878	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					12.5	1.9790	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		SSP-T7-FL			3.7	0.2332	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					4.4	0.3095	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					6	0.5247	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
	EPSON	MC-164 32.768000kHz 7		0.8	7	0.6705	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		MC-164 32.768000kHz 9			9	1.0585	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		MC-164 32.768000kHz 12.5			12.5	1.9496	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
	ECS	ECS-.327-6-38-TR			6	0.5096	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ECS-.327-7-38-TR			7	0.6705	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-9-38-TR			9	1.0585	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		ECS-.327-12.5-38-TR			12.5	1.9496	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
	CITIZEN	CM130			6	0.5096	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					7	0.6705	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					9	1.0585	F0, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					12.5	1.9496	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5

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

Package size	Manufacturer	Quartz ref / Part number	ESR max (kΩ)	C_0 (pF)	C_L (pF)	g_{mcrit}[1] (µA/V)	STM32 Series compatibility[2][3]
8.0 x 3.8 mm	ECS	ECS-.327-6-17X-TR	50	1.35	6	0.4580	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ECS-.327-12.5-17X-TR			12.5	1.6263	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
	CITIZEN	CM200C			6	0.4580	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
					7	0.5911	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					9	0.9081	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
					12.5	1.6263	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
	EPSON	MC-306 32.768000kHz 7		0.9	7	0.5291	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		MC-306 32.768000kHz 9			9	0.8309	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		MC-306 32.768000kHz 12.5			12.5	1.5223	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
	ABRACON	ABS25-32.768kHz-6-T	50	1.35	6	0.4580	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1
		ABS25-32.768kHz-T			12.5	1.6263	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
10.4 x 4.0 mm	EPSON	MC-405 32.768000kHz 7	50	0,85	7	0.5224	F0, F1, F2, F3, F4, L0, L1, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		MC-405 32.768000kHz 9			9	0.8225	F0, F1, F3, F4_g2, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, U5
		MC-405 32.768000kHz 12.5			12.5	1.5110	F0, F3, L0, L4, L4+,L5, G0, G4, F7, H7, WB, WL, MP1, 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.

Note: *MCUs of the STM32U5 Series do not support crystal / MEMS resonators with CL ≤ 6 pF.*

6 Recommended crystals for STM8AF/AL/S microcontrollers

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

Table 9. NDK compatible crystals (not exhaustive list)

Part number	Frequency	ESR max	C_L	Drive level (DL)
NX8045GE STD-CJL-6	4 MHz	150 Ω	8 pF	500 µW max
	8 MHz			
NX5032GA STD-CSU-1	8 MHz	300 Ω		
NX8045GB STD-CSJ-1	8 MHz	220 Ω		500 µW max
	16 MHz	150 Ω		
NX3225GA STD-CRA-1 NX3225GB STD-CRA-2	16 MHz	120 Ω		200 µW max
NX3225SC STD-CRS-1 NX3225SA STD-CRS-2				
NX5032GA STD-CSU-2				
NX5032SD STD-CSY-1	16 MHz	100 Ω	12 pF	100 µW max

Note: *Contact provider regarding recommended crystals for new design.*

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

The 32 kHz crystal oscillator is an ultra-low-power oscillator (transconductance of a few µA/V). The low oscillator transconductance affects the output dynamics since smaller transconductance values generates a smaller oscillating current. This results in a lower peak-to-peak voltage on the oscillator outputs (from a few dozen to a few hundred mV).

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 in order 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 that should be taken when designing the oscillator PCB is provided below:

- High values of stray capacitance and inductances should be avoided as they might lead to uncontrollable oscillation (e.g. the oscillator might resonate at overtones or harmonics frequencies). Reducing the stray capacitance also decreases startup time and improves oscillation frequency stability.

- To reduce high frequency noise propagation across the board, the microcontroller should have a stable power supply source to ensure noiseless crystal oscillations. This means that well-sized decoupling capacitor should be used for powering the microcontroller.

- The crystal should be mounted as close as possible to the microcontroller to keep short tracks 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 might affect oscillation stability.

  Long tracks/paths might behave as antennas for a given frequency spectrum thus generating oscillation issues when passing EMI certification tests. Refer to *Figure 14* and *Figure 16*.

- Any path conveying high-frequency signals should be routed away from the oscillator paths and components. Refer to *Figure 14*.

- The oscillator PCB should 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 microcontroller ground. It prevents interferences between the oscillator components and other application components (e.g. crosstalk between paths). Note that if a crystal in a metallic package is used, it should not been connected to the oscillator ground. Refer to *Figure 13*, *Figure 14* and *Figure 15*.

- Leakage current might increase startup time and even prevent the oscillator startup. If the microcontroller is intended to operate in a severe environment (high moisture/humidity ratio) an external coating is recommended.

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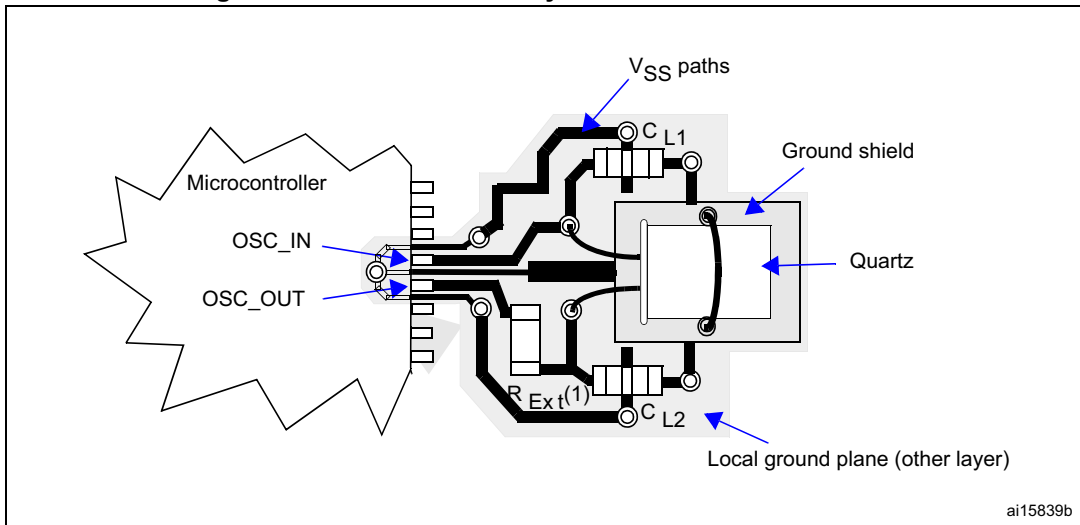
Warning: **It is highly recommended to apply conformal coatings to the PCB area shown in *Figure 13*, especially for the LSE quartz, CL1, CL2, and paths to the OSC_IN and OSC_OUT pads as a protection against moisture, dust, humidity, and temperature extremes that may lead to startup problems.**

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
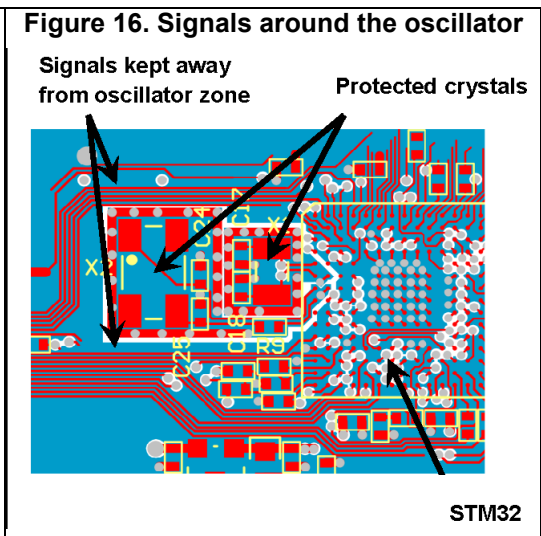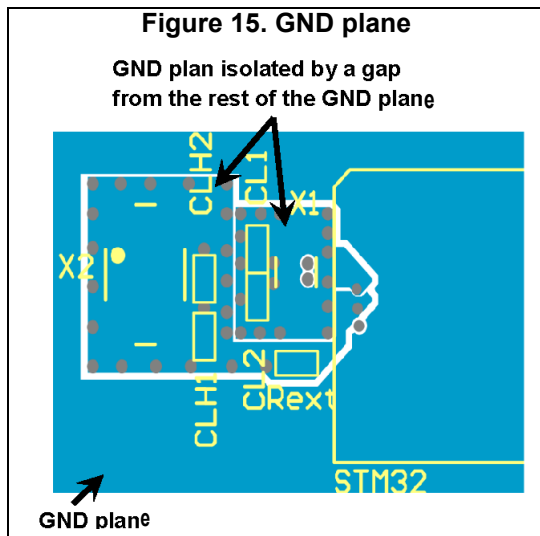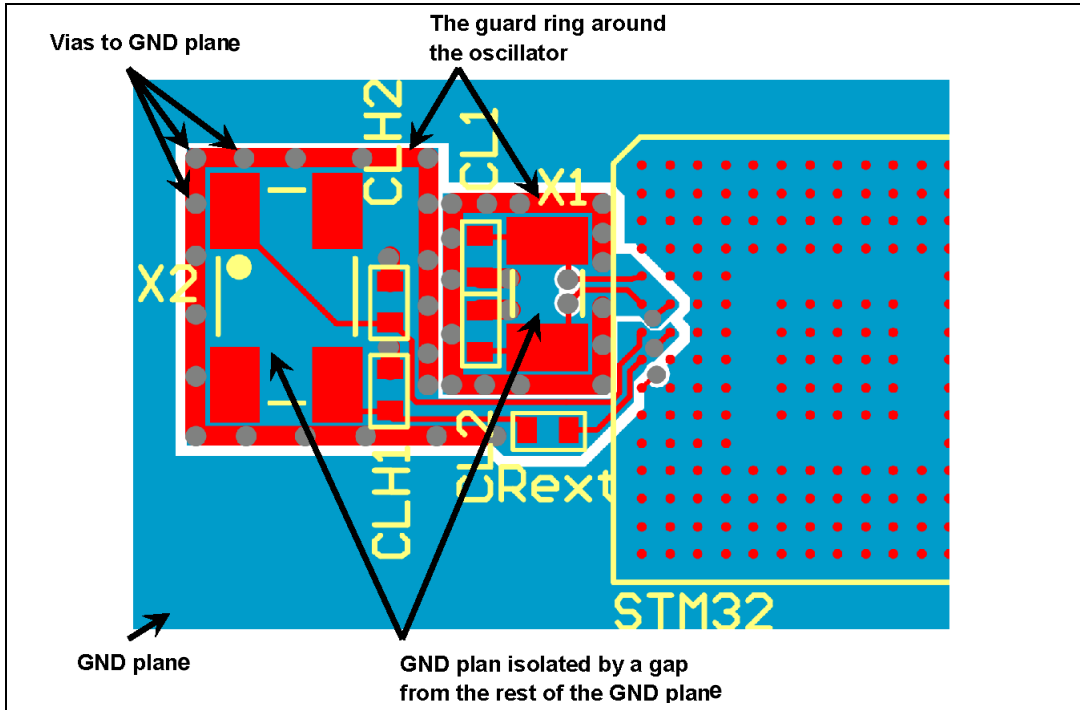
Example 2

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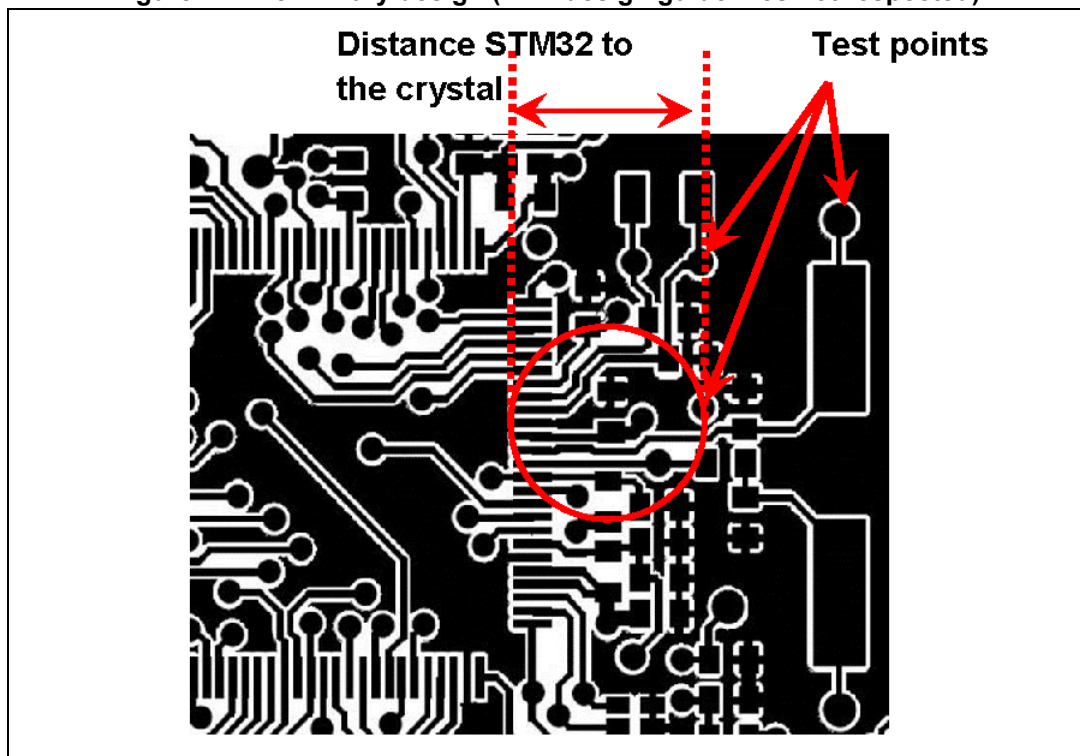
The PCB design has been improved according to the guidelines (see *Figure 18*):

- 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)
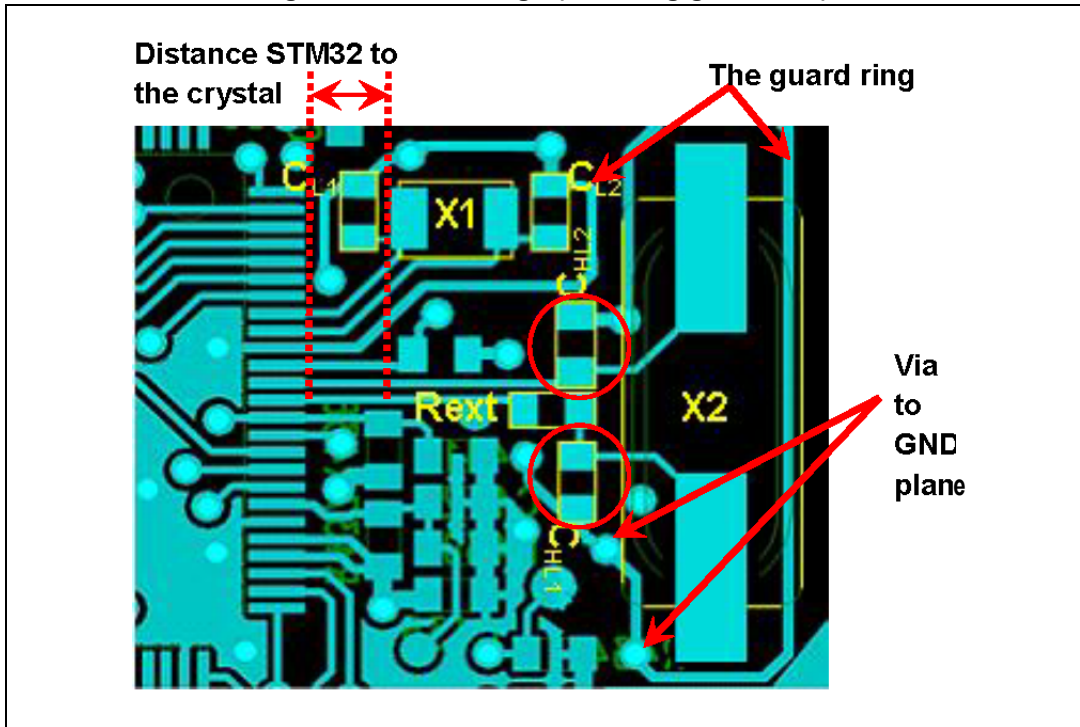
Figure 19. GND plane
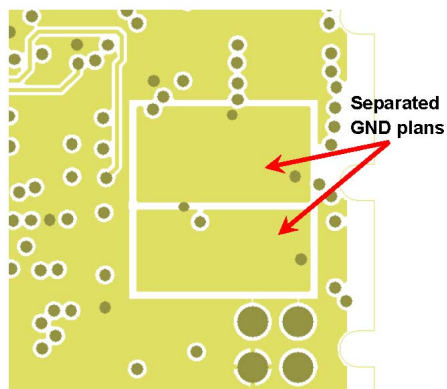
Figure 20. Top layer view
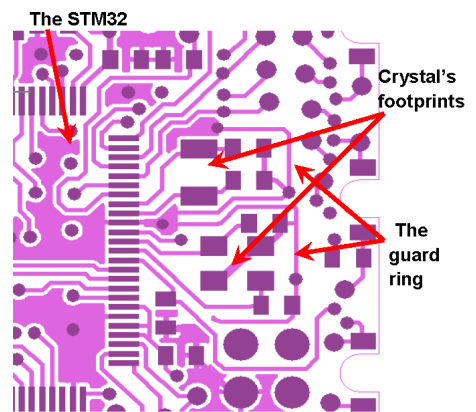
Example 3

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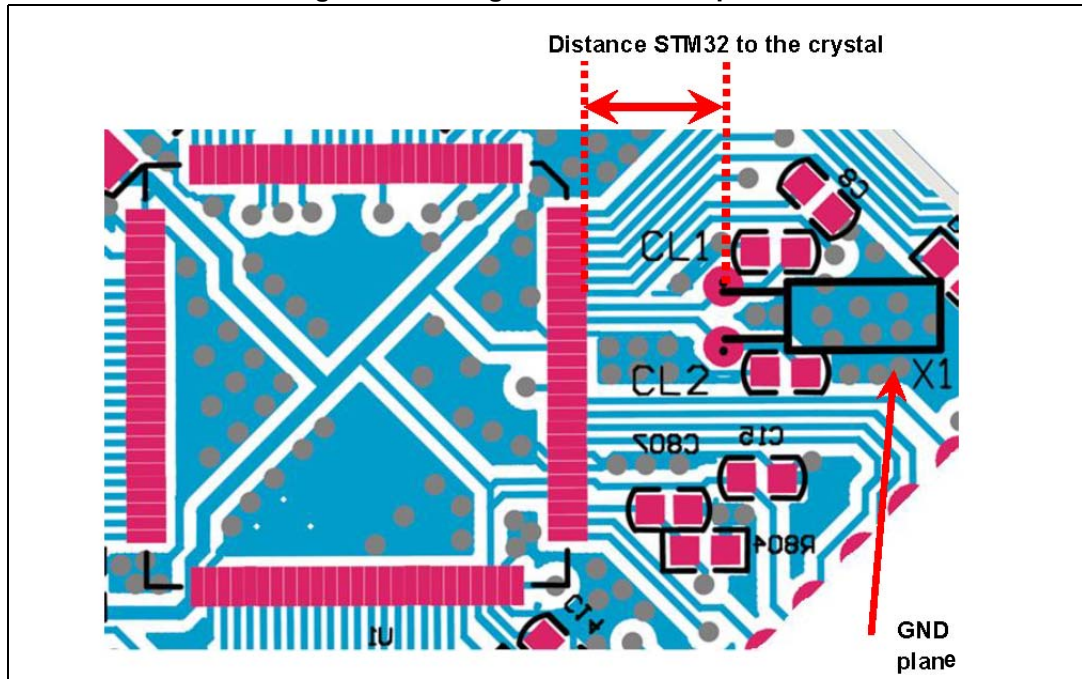
The layout has been improved to respect the guidelines (see *Figure 22*), EMC tests are likely to be passed:

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

Figure 22. PCB guidelines respected
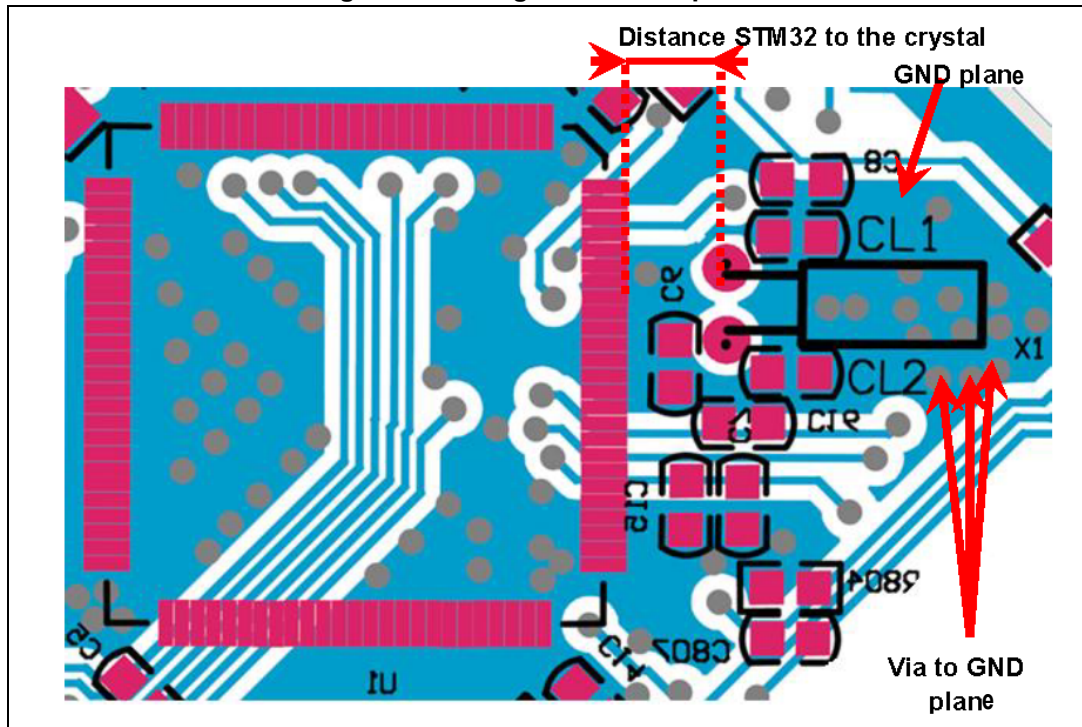
7.3 Soldering guidelines

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) 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 it may disturb 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 has to be calculated at the beginning of the design phase to choose the suitable crystal 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 of the crystal. 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 the user should 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, the latter should be configured 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 NEW LANDSCAPE TABLE*. 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 microcontrollers*, 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.

IMPORTANT NOTICE – PLEASE READ CAREFULLY