How to Choose the Right Crystal - Is the size alone decisive?

Design Hints using Quartz Crystals

Due to fast evolving and highly competitive industry sectors, the requirements for components are stringent: small, low power consuming, and cost effective.
In the previous two documents of this series we provided an overview of the different types of crystals and oscillators, a short guide on which product to choose when, and some basic engineering rules and design parameters. In this document we will take one step further and show how to choose the right crystal for your design, keeping in mind the technical and commercial requirements.

Design Goal

Often the search and choice of frequency generating components is limited to the recommendation of the IC manufacturer and the price competitiveness on the market.
Taking one step back, one should consider what the design goal is and what is needed to fulfill it.

In a nutshell, the role of a Quartz Crystal in a design can be simplified as follows:
- Generates a stable oscillation
- Provides compatibility with the IC/MCU that is used on the board
- Maintains accuracy over temperature and time
- Ensures reliability and longevity

What is needed to fulfil this role? A crystal matching the main criteria as already defined in the previous article: frequency, load capacitance, package type, tolerance etc.
We have summarized the main decisive technical parameters in a checklist (table 1), adding examples and the meaning for the design, while focusing mainly on current SMD components rather than older package types.

Check	Details	Result if Passed
Define Frequency	Match IC/system requirement (e.g., 32.768 kHz, 8 - 25 MHz, RF frequencies)	Correct frequency generation
Check Load Capacitance (C_L)	Ensure crystal CL matches IC requirement (e.g., 8 pF, 12.5 pF, 16 pF, 18 pF, 20 pF)	Stable oscillation at intended frequency
Choose Package Type	SMD (2510, 3225, 5032) depending on PCB size.	Mechanical fit and assembly compatibility
Check Tolerance & Stability	Initial accuracy (±10-50 ppm), stability over temperature (±30 ppm typical, ±15 ppm more often required)	Accurate and stable clock across conditions
Verify Drive Level	Ensure IC drive level is within crystal rating (100-300 µW typical)	Crystal not overstressed, reliable operation
Select Temperature Range	Commercial (-20° ~ +70°C), Industrial (-40° ~ +85°C), Automotive/Military (-40°/-55°C ~ +125°C)	Operates across required environment
Application-Specific Check	e.g, RTC (32.768 kHz), MCU (8 - 50 MHz), RF (high frequency, tight tolerance)	Crystal matches intended application
Confirm with Datasheet	Cross-check IC oscillator specs with crystal datasheet for compatibility	Compatibility and reliability confirmed
Check Gain & Phase (Oscillator Stability)	Ensure loop gain ≥ 1 and phase shift ≈ 0° (via simulation or analyzer)	Oscillator reliably starts and sustains oscillation

Component Selection

Coming back to the market requirements regarding devices and hence components: small, low power, cheap. Is size really all? What are the drawbacks of a crystal in a small package?

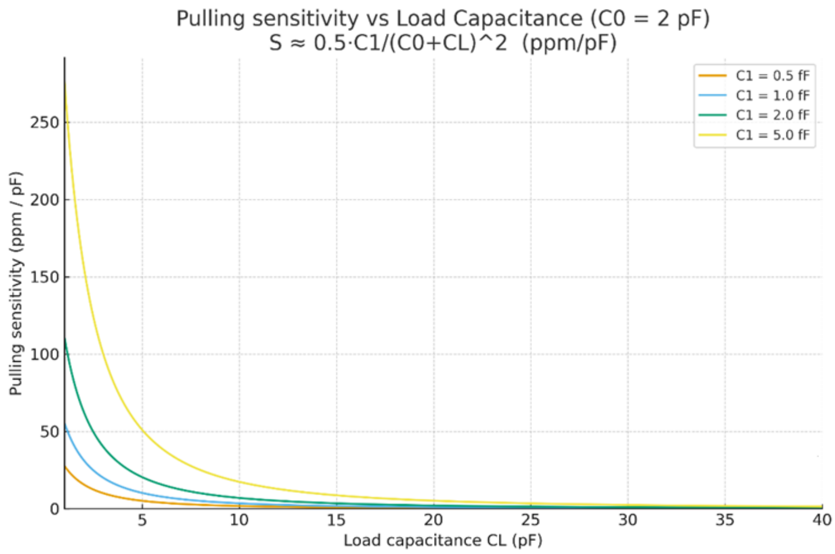
We compared three different SMD crystal package sizes with respect to parameters that are influenced by size. You will find the summary in table 2 below.

Feature	2016 (picking up for new designs)	3225 (currently high runner)	5032 (still highly in use)
Footprint	2.0 × 1.6 mm	3.2 × 2.5 mm	5.0 × 3.2 mm
Common frequency band	16 - 80 MHz	8 - 80 MHz	8 - 80 MHz
Typical load capacitance (C_L)	8 - 16 pF	7 - 20 pF	10 - 20 pF
ESR (typical)	40 - 200 Ω	20 - 150 Ω	10 - 80 Ω
Drive level (max)	100 - 200 µW	100 - 300 µW	100 - 500 µW
Pulling sensitivity (ppm/pF) same C_L	Lower (≈0.5 - 1.0)	Medium (≈0.8 - 1.5)	Higher (≈1.2 - 2.0)
Trimming sensitivity	Lower – small blank, less responsive to trim caps	Moderate – allows useful frequency trimming	Higher – more sensitive to trim caps, easier to adjust frequency
Electrical impact	Higher ESR → harder to drive; less pulling effect from load capacitance	Balanced ESR and drive handling; moderate pulling effect	Lower ESR → easy start-up; higher pulling effect (more sensitive to C_L)
Mechanical note	Very small, good for IoT/wearables, less robust	Industrial #1 robust and widely used	Very robust, stable under vibration/temperature
When to pick it	When space is premium and low drive is okay	General-purpose choice across industries	General-purpose choice across industries

An important role in the choice of the crystal is the pulling sensitivity, often referred to as the trimming sensitivity, although there is a difference between the two. While the pulling sensitivity is an intrinsic raw crystal property, the trimming sensitivity is an application-level measure describing how well the frequency can be fine-tuned in the oscillator circuit.

The pulling sensitivity $C_1 x 10^6/2(C_0+C_L)^2$ (ppm/pF) describes how much the crystal's oscillation frequency changes when the load capacitance changes. It depends on C_1 (motional capacitance), C_0 (shunt capacitance) and C_L (load capacitance).

The trimming sensitivity is defined as the frequency change (ppm) per unit change in trimming capacitor (pF) in the oscillator circuit. It includes the pulling sensitivity and the effect of the oscillator topology and capacitor arrangement.



In the graph, we depicted the dependency of the Pulling sensitivity with respect to the load capacitance at C_0=2 pF.

One can see that for larger C_1 (larger crystal blanks), the pulling sensitivity is higher, i.e. the crystal frequency moves more per pF change in C_L. Increasing C_L reduces how much frequency moves for the same trim error.

So, a design trade-off: larger C_1 (typical for larger packages) means easier to trim in-circuit but also more sensitive to layout and stray-capacitance changes; increasing C_L reduces sensitivity but can affect the oscillator start-up.

Concluding, balancing a low ESR with the right C_L, while keeping a good pulling range for smaller package sizes, is a challenge that the quartz manufactures have taken, being able to solve the technicalities of a wide range of applications.

Still, for every demanding design one needs to balance the technical requirements vs the space and power constraints.

Design Verification

The best way for an engineer to choose the right crystal for his design is to simulate the behavior in an oscillator circuit using a simulation program like the GEYER Y-Quartz App. This simulation process does not take long, it allows you to check the accuracy of your parameters in advance and save valuable design effort on paper or in hardware.

In the simulation you can modify the crystal inherent parameters and the oscillator dimensioning until the oscillator circuit provides the optimum phase noise and gain, both a measure of the oscillator stability.

A typical design using the App requires following input parameters:

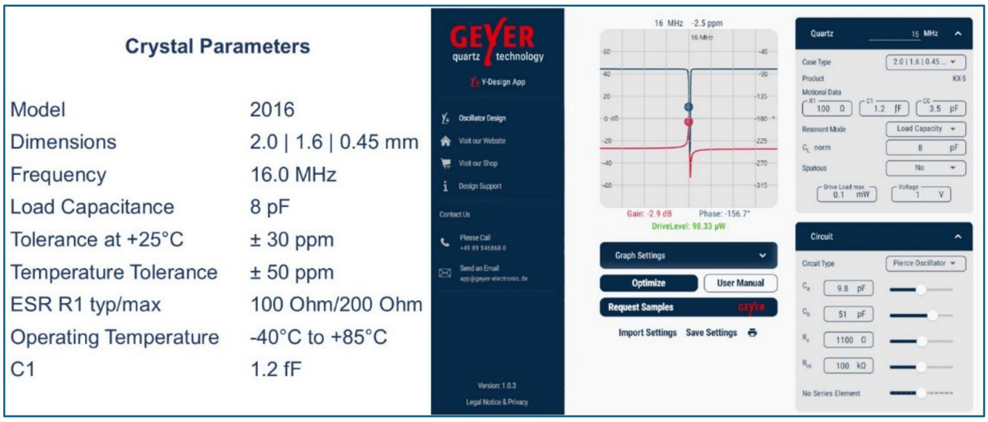
f_L	Nominal frequency of Quartz crystal
R1	ESR of Quartz crystal (usually specified as upper limit)
C_0	Static capacitance of Quartz crystal (usually specified as upper limit)
C_1	Dynamic (motional) capacitance of Quartz crystal (rarely specified)
C_L	Nominal load capacitance of Quartz crystal
L1	Dynamic inductance of Quartz crystal (rarely specified)

These values are specified in the datasheet of the component. Exact values can be found by analyzing a batch of Quartz crystals with a network analyzer.

Linking theory to reality, we have chosen a simulation example reflecting a quite common, simple application.

Simulation example for a coffee maker using a 2.0 x 1.6 mm, 16 MHz crystal

Taking the example of Coffee Machines, which either work standalone or integrated in a Smart home environment, you can simulate and optimize the characteristics of a Pierce Crystal oscillator by inputting the corresponding values. You can visualize and vary the amplitude and phase characteristic of the feedback circuit, consisting of the quartz crystal and surrounding components, for reliable oscillation without exceeding the maximal drive level of the crystal.
The simulation gives you initial feedback regarding the type of crystal that you need and the oscillator design performance.



Once the component parameters have been defined, the engineer usually requests samples from the crystal manufacturer and verifies them on his evaluation board, performing the final tuning of the oscillator part. Some manufacturers offer consulting, reference designs and prototyping support.

Bottom Line

With the right crystal choice and design discipline, you unlock precision, stability, and trust in every clock cycle:

- Select the right package size to balance compact design with long-term reliability
- Ensure the oscillator and crystal are matched for robust start-up and stable performance
- Apply best-practice PCB layout rules to safe guard frequency accuracy and low jitter
- And last, but not least: after the simulation, test in real HW your timing design

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