

CLOCKING MADE CLEAR: Quartz Crystals vs Oscillators

Designs with frequency components are not difficult but still often underestimated.

In the first document of this series we provided an overview of the main quartz crystals and oscillator types and their basic design parameters. In this document we will present some basic engineering rules to follow in designs.

Component role and choice

Both quartz crystals and oscillators are used to generate clock signals in electronic circuits, but they serve slightly different roles:

- A **Quartz Crystal** is a piezoelectric resonator that vibrates at a certain frequency when excited electrically. It requires external circuitry to act as an oscillator.
- An **Oscillator** is a self-contained module that includes the crystal and the circuitry, producing a ready-to use clock signal.

As a **rule of Thumb**:

- Use a **crystal** if you need a cost effective BOM, if your frequency is moderate (kHz – tens of MHz), where power consumption is critical.
- Use an **oscillator module** if you need higher frequencies, better stability, when board simplicity matters (no loading capacitors, no drive level issues, just simple plug -and play).

Another criterion for choosing the right component is the circuit requiring the clock from the crystal:

- If your board contains MCUs/SoC – then the crystal design is all about reliability of start-up, tolerance and low-power modes.
- If you work with FPGAs/SerDes – then the oscillator selection is about jitter budget, signal integrity and reference clock compliance.

Most Common Design Parameters

Selecting the right component for the application is not an easy task. It is more than “frequency = X MHz”. The choice is based on the technical requirements of the application, on the target cost of the system, and ultimately on the business case.

Focusing on the primary technical aspect, we summarized the main considerations for design parameters in the table below.

Category	Parameter	Description
General	System Frequency Tolerance Budget	Combined budget = initial + temp + aging within system spec
General	Multi-Vendor Availability	Part available from at least two vendors
General	Lifecycle Status	Part not NRND/EOL; has long-term availability
General	Reference Design Alignment	Matches IC vendor reference design guidance
Crystal	Frequency	Target operating frequency
Crystal	Load Capacitance (C _L)	Matches oscillator circuit requirement (MCU DS)
Crystal	ESR	Crystal ESR must be below IC's max to ensure startup
Crystal	Drive Level	Stay below crystal's max drive (typically <100µW)
Crystal	Tolerance (25 °C)	Initial accuracy (ppm) at 25 °C

Crystal	Temp Stability	Frequency variation over operating temperature range
Crystal	Aging	Long-term drift per year (ppm)
Crystal	Startup Time	Startup time must meet MCU wake/warmup budget
Crystal	Package & Height	Check size and profile fit PCB and enclosure
Crystal	Operating Temp Range	Consumer, industrial, or automotive rating
Crystal	Shock/Vibration Tolerance	If rugged or automotive design requires it
Oscillator	Frequency	Target refclock frequency (e.g., 25, 50, 100 MHz)
Oscillator	Output Type	Output format: CMOS, LVDS, LVPECL, HCSL, etc
Oscillator	Output Voltage Levels	Check V_{IH}/V_{IL} or V_{OD} match with receiver logic levels
Oscillator	Stability (ppm over temp)	Frequency stability across temperature range
Oscillator	Jitter / Phase Noise	Meets jitter budget for SerDes, PCIe, Ethernet, etc
Oscillator	Startup Time	Startup must meet FPGA/PHY lock time requirements
Oscillator	Aging	Frequency drift over time within spec
Oscillator	Supply Voltage	Supply voltage compatibility (1.8 V, 2.5 V, 3.3 V)
Oscillator	Current Consumption	Oscillator current consumption within system budget
Oscillator	Package & Pinout	Package dimensions and pinout compatibility
Oscillator	Operating Temp Range	Environmental spec: consumer, industrial, auto
Oscillator	TCXO/OCXO Options	Consider for GPS/telecom precision applications

Choosing the right component is the first hurdle to take, however it does not guarantee the quality of the design. For this purpose, we compiled a basic checklist with simple rules that should be taken into consideration in the design phase of the oscillator section of your application board. It also highlights very well the differences between the designs with crystals and those using oscillators.

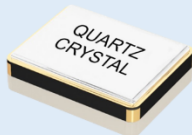
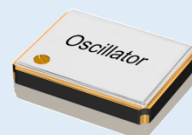
Checklist matrix crystal & oscillator design

Rule	MCU/SoC + Crystal	FPGA/SerDes + Oscillator	Notes/Suggestions
Vendor ref design cross-check	✓	✓	Always reconcile against the specific IC note
Place close to clock pins	✓	✓	Keep loop/trace short; <~5–10 mm target
Short, symmetric routing	✓	✓	Avoid vias; symmetry matters more for crystals
Keepout from noisy nets	✓	✓	No DC-DC switch nodes, USB/DDR under/near
Solid ground under device	✓	✓	No split planes; dedicated GND vias by caps
Load caps calculated incl. parasitics	✓	–	Include pad/trace/MCU pin (3–5pF typical)
Individual GND vias for load caps	✓	–	Don't daisy-chain returns
Crystal drive level checked	✓	–	MCU drive < crystal max; prevents aging/start fail
Startup margin across PVT	✓	✓	Worst-case V_{min}/T_{min} ; check datasheet startup time
Guard ring (optional)	✓	–	Grounded copper around XTAL nets on noisy boards
Output format matches receiver	–	✓	CMOS/LVDS/HCSL/LVPECL; check V_{IH}/V_{IL} or V_{OD}
Jitter/phase-noise meets budget	–	✓	Map to spec (PCIe/Eth/SDI/SerDes)
No unintended clock fan-out	✓	✓	Use buffers; don't T-split unless specified
Power-on sequencing verified	✓	✓	Checked against FPGA/PHY power-on reset timing

Decoupling at supply pin	–	✓	1 nF + 10 nF at V_{CC} ; shortest loop
Local rail filtering (ferrite/RC/ π)	–	✓	Helps jitter; place before V_{CC} pin
Controlled-impedance clock trace	–	✓	Critical >50–100 MHz or long runs
Series source termination	–	✓	small resistor (20-30 Ohm) near XO to prevent ringing/over-shoot
Case/ground pad stitching	–	✓	Multiple vias to GND; reduces EMI/susceptibility
Thermal isolation from heat	–	✓	TCXO/OCXO stability; avoid regulators/VRMs

Summary

Although there is no strict rule when to use crystals and when to use oscillators, we could simply conclude with Pros and Cons for both component types, as depicted in the picture below.

Quartz Crystal	Oscillator
 Pros • Lower Cost • Very Low Power • Wide availability in standard frequencies Cons • Require external oscillator circuit • Sensitive to PCB layout, parasitics and noise	 Pros • Self-contained, plug-and-play clock source • Available in higher frequencies • Stable, predictable performance Cons • Higher Cost • Higher Power Consumption • Larger package sizes

In our next article, we will concentrate on quartz crystals and the important points to consider when using them in a design.