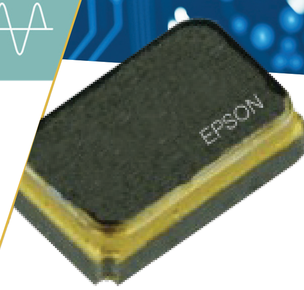


# The Designer’s Guide to:

## Common Considerations When Selecting a kHz Crystal

PART I

# Introduction to Crystals and Trends

Billions of crystals are manufactured every year via a high-precision process, and can be used in virtually every electronic device in any industry. Crystals support all types of devices and networks, from simple display clocks to high-speed, high-capacity telecommunications. They are the cornerstone of many products we depend on every day.

Crystals are a key component of electronic oscillator circuits, which create electrical signals with precise frequency. This frequency provides a stable clock signal for digital integrated circuits, and to stabilize frequencies for radio transmitters and receivers. They can be manufactured for frequencies from a few tens of kilohertz (kHz) to hundreds of megahertz (MHz).


PART II

# Wide Range of Timing Products

There are many timing products on the market to choose from, but the most common classifications for timing devices are crystal or oscillator in kHz or MHz frequencies. kHz crystals are sold as standalone crystal units and are also integrated into other products, like simple package crystal oscillators (XOs), temperate compensated XOs and real-time clocks (RTC). You may also know kHz crystals as Tuning Fork Crystals and Clock Crystals (32.768 kHz). 32kHz crystals are used in most electronics across all the major markets and applications in IoT, industrial and factory automation, automotive, and networking. All these applications have at least one MCU or processor and possibly an external RTC for time keeping, clocking, watchdog timer, etc. These functions require 32kHz.

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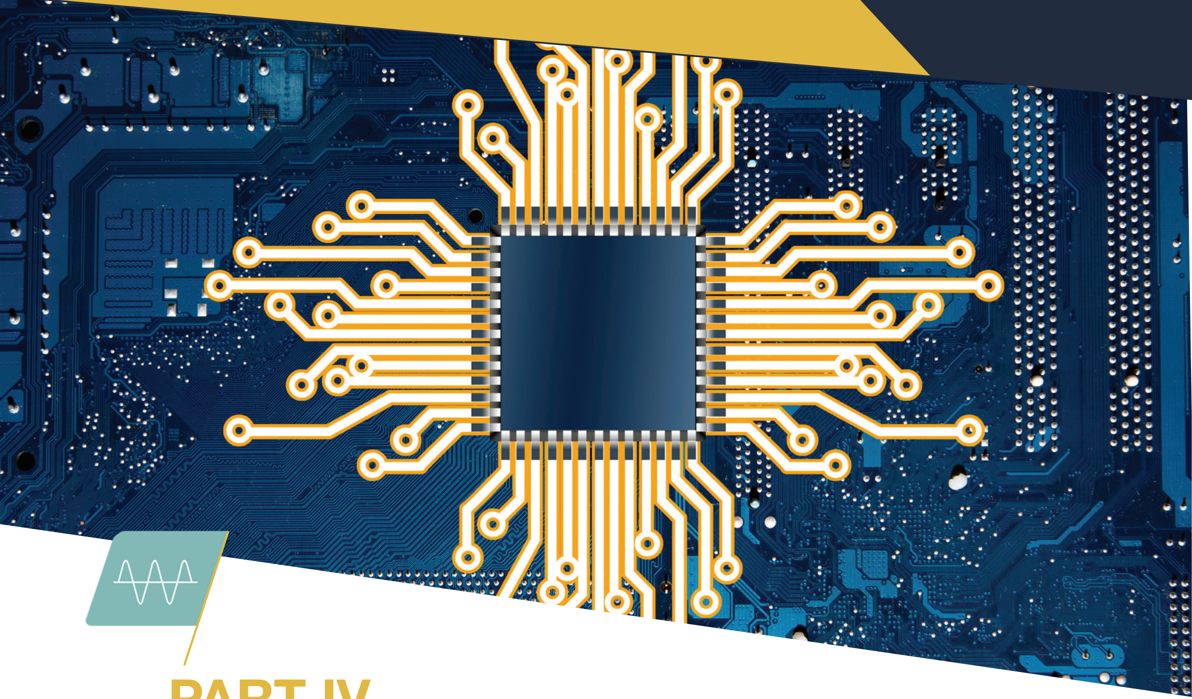
PART III

# Choosing the Right kHz Crystal for Your Design

When choosing a kHz crystal, there are a variety of technical specifications to consider. The two to consider immediately are the size and frequency. **However, a few others also to look into include:**

- Crystal frequency, frequency tolerance, stability, and aging
- Load capacitance (CL)
- Equivalent series resistance (ESR)
- Drive level (DL)
- Operating temperature

These days, there is a trend toward crystal miniaturization, which makes it more challenging to honor current crystal specifications. However, Epson's photolithographic process makes it possible to miniaturize while maintaining — or even improving — key specification parameters.



## PART IV

# Common Considerations When Selecting a Miniaturized kHz Crystal to Save Board Space

### Crystal frequency, frequency tolerance, stability, and aging

Crystal frequency error is dependent on frequency tolerance, frequency stability, and aging. To understand crystal frequency error, it's important to be familiar with the below terms.

**Frequency** — The nominal frequency of the crystal according to its specification.
**Frequency Tolerance** — The difference between the actual frequency of the crystal from the nominal frequency value at +25°C.
**Frequency Stability** —The maximum frequency shift due to temperature across a given temperature range.
**Aging** —The maximum frequency drift expected in a crystal over time. Most crystal aging happens within the first few years, with the aging decreasing over time.

Designers should consider aging for the amount of change in frequency and other characteristics that occur over time. **Causes of frequency variation include:**

- Strain due to stress on surfaces during crystal manufacturing processes
- Strain due to stress at the mounting point
- Changes in the package's internal gasses

Frequency tolerance, frequency stability, and aging are the biggest factors in any deviation from the desired nominal frequency. When reviewing industry standards and ASIC requirements, remember that they usually specify the maximum frequency error requirements without considering the system temperature or lifetime. It's critical to account for any errors in these factors. For

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example, let's say you have a crystal in your car clock, and the weather outside is a chilly 15°F (-9.4°C), compared to a room temp of 77°F (25°C). Because the crystal has a temperature dependency, external weather conditions will influence the dependency, which changes the frequency of the crystal and thus the time shown on the dashboard.

The accuracy of any conventional kHz XO is determined by the frequency vs. temperature accuracy of a kHz tuning-fork crystal. Conventional kHz crystals and oscillators generally specify accuracy, for example +/-20ppm, only at room temperature.  At temperature extremes like +105 °C, the accuracy is close to -225 ppm, which is ~10 minutes per month. More and more applications are using the kHz clock to generate the system's main timebase. If you want more accurate time, consider a kHz XO with higher stability.

Epson has temperature compensated 32.786kHz XOs and RTCs for applications in harsh environments such as automotive and industrial. Epson's DTCXO technology helps calibrate and optimize the internal oscillator and kHz crystal combination to achieve the high accuracy, only ~20 seconds per month, at the same +105 °C.

Epson kHz crystals get smaller, but the frequency specifications remain the same (f_nom, f_tol, B for calculating stability, aging), thanks to our photolithography process. However, the other topics in the subsequent sections should be considered in tandem with these specifications.

**Best Practice:** Understand the ASIC requirements for maximum frequency error and the product life expectancy. Partner closely with the crystal supplier to check that the maximum frequency error covers the full scope of your project needs.

## The smaller the crystal, the more sensitive to capacitive changes, which shifts the frequency.

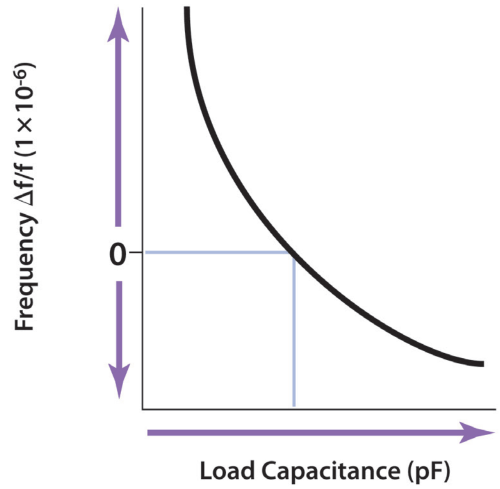
### Load Capacitance (CL)

A crystal's load capacitance is the capacitance measured between the two terminals of the crystal. The recommended oscillation circuit specifies the CL value. The crystal's frequency is normalized to that expected load capacitance.

If there's a mismatch between the crystal's expected CL and the circuit's capacitance, it will cause an unwanted frequency shift. The ASICs used will often specify the crystal's load capacitance, but designers still need to fine tune and account for their oscillation circuit's capacitance, including stray and other sources of parasitic capacitance in the design. This "matching" process involves selecting the appropriate external capacitors (Cg and Cd) so that the oscillation circuit's total capacitance matches the crystal's expected CL.

$$\mathbf{CL} = \frac{\mathbf{CG \times CD}}{\mathbf{CG + CD}} + \textbf{CS (Stray capacity)}$$

**Frequency vs. load capacitance (CL)**




Depending on the application, some ASICs specify a crystal with lower CL (<6 F) for faster startup and lower power. However, this also means that the crystal frequency is highly sensitive to changes in the oscillation circuit's capacitance, which can drastically change the frequency output. Conversely, some ASICs specify a crystal with larger CL (>9 pF) for a more stable oscillation. In some cases, designers may need to choose a crystal CL different from the ASIC's recommendation to meet certain performance criteria.

The smaller the crystal, the more sensitive to capacitive changes, which shifts the frequency. This shift in frequency is affected by stray capacitance variations of the entire PCB the crystal is mounted on. If the crystal CL is low, the frequency sensitivity will be high, and if the crystal CL is high, the frequency sensitivity will be low. If small size is important, try to choose large CL value and external caps with less variation.

**Best Practice:** Understand the relationship of the crystal's CL with the oscillation circuit capacitance, including board strays, to achieve optimal frequency output. Crystal suppliers can provide a Frequency vs. CL graph (crystal sensitivity curve) upon request. Epson offers a complementary circuit evaluation service, which offers designers additional assurance.

## Equivalent Series Resistance (ESR)

Equivalent series resistance (ESR), or motional resistance, is more commonly known as "the resistance to oscillation." ESR is a critical component in the Barkhausen condition, which is required for stable oscillation. The higher the ESR value of the crystal, the more difficult to maintain oscillation. Many crystal and ASIC manufacturers recommend significant oscillation margin, perhaps 5x, above the ESR maximum value in order to meet the Barkhausen condition. This helps ensure oscillation in any environment. The recommended ESR value is typically specified by the ASIC, though some applications in rigorous environments may choose a lower ESR.

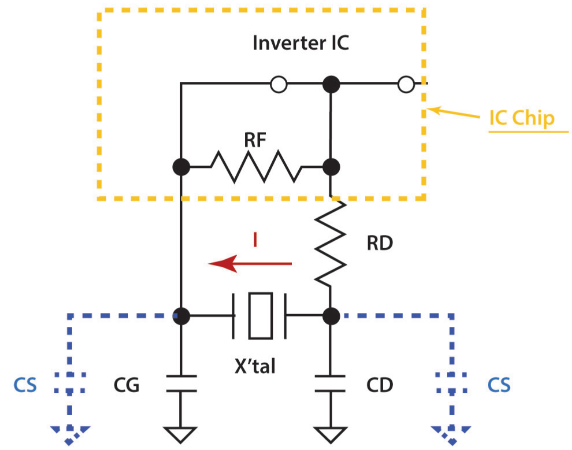
ESR is largely determined by the size and frequency of the crystal. As size and frequency decrease, ESR increases. Some designers may choose a smaller crystal package to save board space, but they will then need to account for the increase in ESR to avoid risks of unstable or no oscillation.

**Best Practice:** Honor the ESR requirements of the ASIC, even if you need a smaller size crystal. Some suppliers can optimize a crystal's ESR beyond the standard specification and offer a complementary circuit evaluation to measure the circuit's oscillation margin.

## Drive Level (DL)

Drive level refers to the current available at the electrodes of the crystal unit. For kHz crystals, 0.1µW to 1µW is the typical range to maintain stable oscillation and minimize structural damage to the internal quartz crystal. Exceeding this value may result in changes in the nominal frequency, erratic behavior of the frequency over temperature, and even catastrophic failure of the crystal unit due to breakage of the quartz plate.

As the crystals get smaller, they require less power to operate. The low-power trend is particularly apparent in sensor networks and eco products, as these promising applications require the ability to operate for long periods of time on batteries.




**Best Practice:** Follow the ASIC's drive level recommendation and select a crystal with a maximum DL specification that meets or exceeds that recommendation. Additionally, measure and verify the DL across the crystal in the circuit. Epson offers a complementary circuit evaluation to check for risks of frequency shift or breakage.

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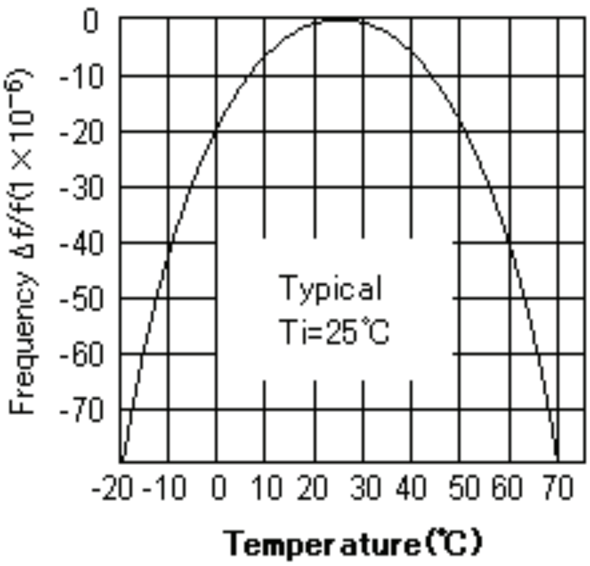
### Operating T emperature

Every electronic device has its own operating temperature range, but designers should also consider the location of the crystal within the design. The ambient crystal temperature within the device could be much higher than the overall system operating temperature — for example, if the crystal is right next to an FPGA or a system fan. The crystal's operating temperature range is related to frequency stability. If a crystal specified for -40 to 85°C is used in an environment that reaches 125°C, there may be additional error outside of the crystal's frequency stability specification. Today, crystals with operating temperatures of 125°C and above are becoming common when it comes to supporting industrial and automotive applications.

**kHz Temperature Curve**




### kHz Temperature Curve

Pay attention to the ambient temperature range of the crystal and select a crystal that meets the frequency stability needs across that range. As value added functions increase and components get smaller, more gets squeezed into tighter areas. This increases heat. Attempts to fit greater functionality into smaller sizes is an industry trend inherent across all electronics.

**Best Practice:** Consider DTCXO or RTC products. The accuracy of any conventional kHz crystal oscillator (XO) is determined by the frequency vs. temperature accuracy of a kHz tuning-fork crystal. Conventional kHz crystals and oscillators are generally temperature-dependent and sensitive to changes in temperature. But industries like IoT, industrial, and automotive require higher accuracy.

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EXCEED YOUR VISION

# Why Choose Epson for Your Crystals and Timing Devices

Epson has the industry's most complete product line of timing devices, spanning crystals and oscillators, including kHz crystals — the crystal used in the world's first ever quartz wristwatch. With a long-standing dominant position in the marketplace and full vertical integration of crystal device production, Epson delivers exceptional product quality, reliability, and consistent availability.

Epson is the most vertically integrated timing company, and one of a few manufacturers that produces our own synthetic Quartz. We're the only manufacturer to design and fab our own ICs, while others outsource one or more fundamental steps in the crystal and oscillator manufacturing process.

Epson's industry-leading vertical integration and our supply chain allow us to control quality, innovation and competitive pricing. In addition, Epson also manufactures all timing products in at least two Epson facilities to provide best-in-class assurance of supply.

**The bottom line:** At Epson, it all comes down to outstanding quality and designing crystals that deliver exceptional reliability. Designers often look at reliability as the most important aspect of their design — and that's why more designers choose Epson crystals and timing devices over any other vendor's offerings.

Learn more about Epson crystals and timing devices at **Epson.com/oscillator-timing-devices** or contact us at **Microdevices@ea.epson.com**