32.768 kHz – More than just a beat

The role of a 32.768 kHz crystal in electronic designs

Using two crystals in the same design – one for the main high-frequency system clock and one for a standby/low-power clock – is a very common pattern in embedded and electronic systems.
Complementing the design aspects and rules that we covered in the 3 previous contributions of this series, we will focus on the role and design aspects for the 32.678 kHz crystal, also known as tuning fork crystal.

What is a tuning fork crystal and why 32.768 kHz?

A tuning fork crystal is a special type of quartz crystal vibrating mechanically in the shape of a tuning fork when an electric field is applied. The tuning fork is formed mechanically from the crystal by sawing or etching and has a different X or XY cut to conventional crystals, which usually show an AT-cut.
Due to their special shape, clock crystals:

- oscillate with a comparatively very low fundamental frequency
- oscillate typically on 32.768 kHz, which is 215 Hz
- are used as real-time clocks and low-power timing
- are stable, low-power, and small
- ensure an improved starting reserve and shorter starting time
- are reliable while having a reduced quartz load
- are not suitable for high-speed applications

Two-crystal designs (main + standby) are extremely common whenever precise timekeeping and low-power operation is needed. They are used in:

- Most micro-controllers with RTC (real-time clock)
- Wireless systems
- Wearables and IoT nodes
- Meters, loggers, clock, and industrial control
- Smartphone and tablets
- Automotive electronics

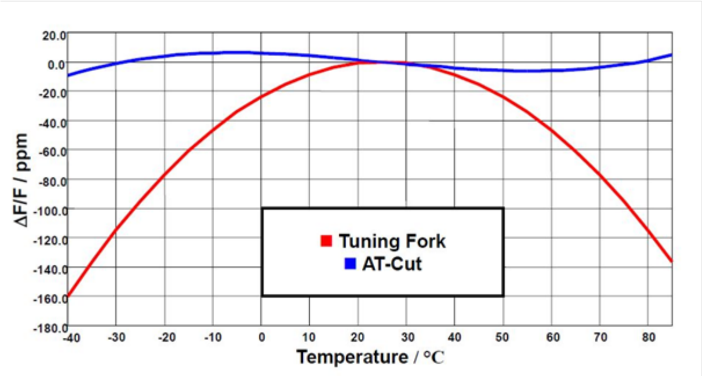
A single crystal is usually used when:

- The MCU has an internal RTC oscillator
- Time accuracy is not so critical (e.g. toys)
- The device does not enter the sleep mode
- High accuracy time stamping is not required

Component selection

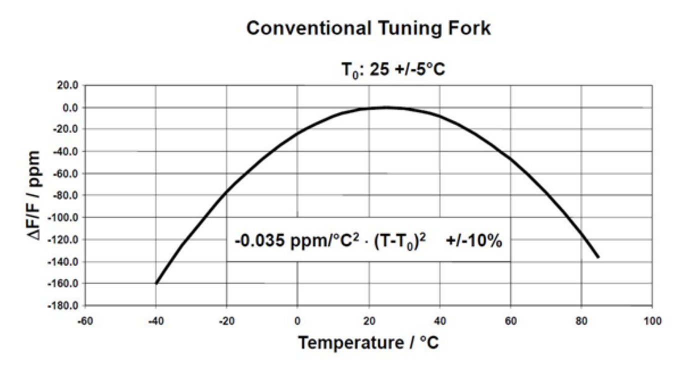
What needs to be considered when selecting a tuning fork crystal?

Besides the regular parameters which are important for a good design with crystals and that we touched on in our previous contributions to the tutorial, there is one particular aspect to be considered for the tuning fork crystal - namely the temperature stability.
While -40°C to +85°C is standard for today, requirements for +105°C and even +125°C are no longer uncommon. Although these temperatures are not a problem for a normal quartz crystal, special attention is required when designing with 32.768 kHz crystals.



From the picture above, one can see that the thermal curve of a tuning fork crystal is totally different to the curve of a regular AT-cut crystal.

The temperature response (frequency deviation over temperature) of a tuning fork quartz is described by the formula: **Deviation [ppm] = –PC [ppm/°C2] · (T-T0)2**, which is a parabola that opens downwards with a vertex at **T0 = + 25°C ±5°C** (reference temperature). [PC = parabolic coefficient]



One can see that the quartz always lags behind as soon as the operating temperature deviates from the reference temperature, and the further away from +25°C, the greater the deviation. At +125°C, this is typically –350 ppm in this case; when all tolerances (e.g. load capacities) are taken into account, it can be significantly higher.

This may not matter in applications where a clock crystal is only keeping a controller alive in standby. However, if the application relies on a precise time base or RTC (Real Time Clock), even the smallest time errors can add up enormously over the year. Several tens of minutes are not uncommon!
The choice of a crystal with greater accuracy does not generally bring the desired success, since the specification of the basic accuracy refers **only** to +25°C. The basic curve therefore does not change.

A solution by hardware, e.g. an adjustment of the circuit by means of adapted load capacitances, is only promising in a narrow temperature range (e.g. wristwatch).

So, what is important after all for obtaining a good design? The answer is: the choice of the component according to the checklist and a **good design verification mechanism.**

Checklist Item	Description
Load Capacitance (C_L)	Match MCU/RTC oscillator requirement (e.g., 6, 7, 9, 12.5 pF)
ESR	Ensure ESR is below MCU's max spec for reliable start-up
Drive Level	Check power handling (typically 0.5–1 µW) to avoid damage
Frequency Tolerance	Initial accuracy at 25°C (±10–30 ppm typical)
Temperature Stability	Frequency drift over temperature (C-curve)
Operating Temperature Range	Match application environment (-40 to +85°C etc.)
Aging	Long-term drift (±3 ppm/year typical)
Package Size	Choose size balancing stability and PCB space
Startup Time	Verify oscillator startup time fits sleep/wake profile
Shock/Vibration Rating	Select robust crystals for wearables/industrial use
Load Capacitors (C1, C2)	Ensure correct values to meet total C_L
PCB Stray Capacitance	Account for trace and pad capacitance (~1–3 pF)

Design verification for tuning fork crystals

For applications that depend on an accurate time base or require precise timing over a longer period of time (e.g. metering/consumption recording), it is essential to **compensate** for the typical temperature curve using software (e.g. look-up table) and, at the same time, **to synchronize** the time at regular intervals **with a master** of some kind (data collector, radio clock, human). Only with these measures can the correct and reliable functioning of the application be guaranteed.

To determine the advantages of lower load capacitance crystals, two clock crystals of 12.5 pF and 7 pF have been compared. The results speak for themselves.

Test criterion	C_L = 12.5 pF	C_L = 7 pF
Oscillator current	3.8 uA	3.4 uA (lower)
Oscillation reserve	6	13 (better)
Start-up time	1.1 s	0.6 s (shorter)
Drive level	2.5 uW	1.2 uW (lower)

However, one disadvantage should not be concealed: Due to the low load capacitance, the oscillator circuit with the 7 pF crystal is more sensitive to component tolerances of the circuitry.

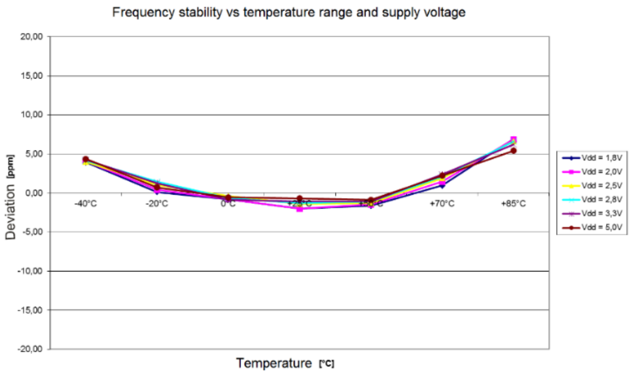
So, if power is an issue use a quartz with a low load capacitance. For applications with higher precision use a quartz with a higher load capacitance.

Alternatives for tuning fork crystals

For higher temperature stability requirements, one can use temperature compensated 32 kHz oscillators as an alternative, either in the 3.2 x 1.5 footprint or as a regular HCMOS oscillator, e.g. 1.6 x 1.2 mm.

Temperature	Quartz	Oscillator
-40 °C	-160 ppm	+4 ppm
+25 °C	0 ppm	-2 ppm
+85 °C	-140 ppm	+7 ppm

From the table on the left, you can see that an alternative crystal oscillator with a current consumption of only 1 µA has a much lower frequency deviation over the temperature and operating voltage range than a clock crystal and may therefore be the better choice for some applications.



Other 32.768 kHz alternatives to the well established tuning forks or 32.768 kHz oscillators have been introduced recently into the maket:

- The **GEYER KX-327ZT** with it's small size of only 1.0 x 0.8 x 0.4 mm completes the GEYER Tuning form family offering a suitable solution for small devices like GPS trackers, smart watches, communication devices, etc.
- The **ultra-low power GEYER TCXO KXO-89@32.768 kHz** is a good alternative to 32.768 kHz components, when it comes to Smart Meters, sensors, long life battery devices, wearables.

Summary

To recap, tuning fork crystals are used in a wide range of applications: Timekeeping devices (e.g. RTCs) or low power applications (e.g. stand-by clock of controllers), sometimes in both (e.g. metering). Often also in applications where costs matter (e.g. toys and gadgets).

Design with tuning fork crystals is not trivial and implies more than just a few hints in this paper.
However, with the right choice of a tuning fork crystal and, if necessary, the correct temperature compensation and master clock synchronization, along with good engineering support, you will see the crystals **"tick"** reliably even in the extended temperature range. Smart alternatives to tuning forks can add another level of precision and stability, where required.