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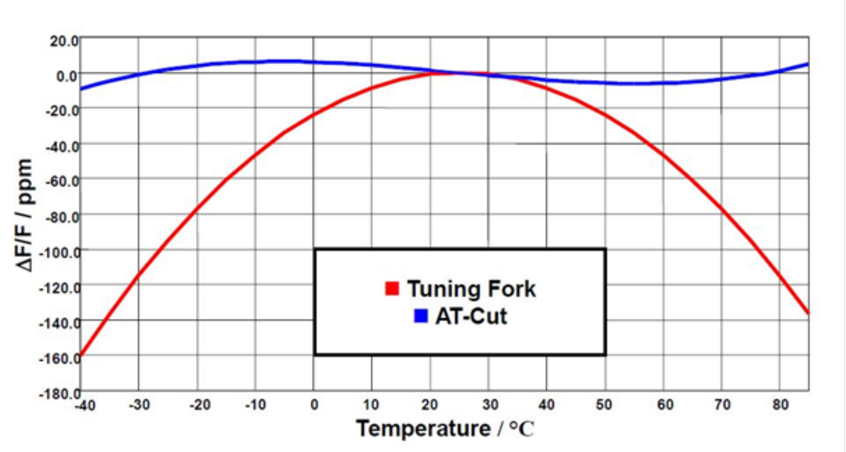
Watch (Clock) Crystals/Tuning Fork Crystals

See them “tick” even in the extended temperature range

If tuning fork crystals are to operate accurately in extended temperature ranges such as -40 °C to +85 °C, for example, in cars, there are some important points to consider in the design.

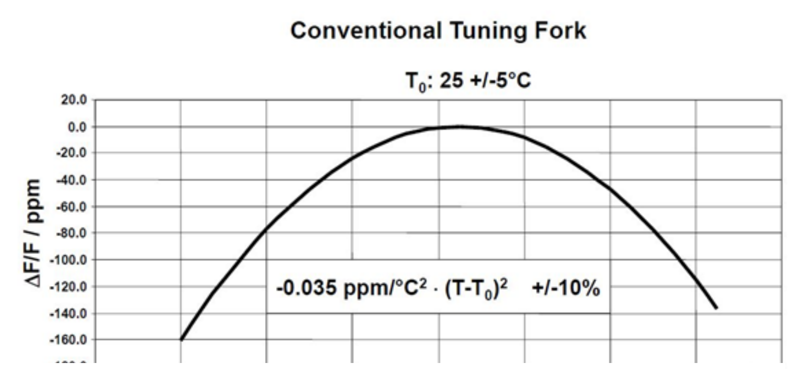


Pic 1: Comparison of AT-cut crystals and tuning fork crystals (principal curve progression)

In the age of increasing networked applications, e.g. in the IoT sector, and the changes in the automotive industry, more and more applications and users are demanding extended temperature ranges for tuning fork crystals. 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 normally not a problem for the pure function of a quartz crystal, special attention is required with regard to designs with watch quartz crystals or tuning fork crystals. Automotive applications, for example, require very high accuracy, which in the extended temperature range proves to be a challenge for manufacturers of tuning fork crystals. It can be seen that operating temperatures, which are not yet an issue for AT cut crystals (the most common quartz cut), can quickly lead to ranges of large deviations for tuning fork crystals. The thermal peculiarities of the tuning fork quartz are often overlooked or insufficiently considered during design, leading to malfunctioning of the application and discontent among users. The quartz is then wrongly attributed a poor quality, although it fully meets the specifications given in the data sheet.

BASICS

The temperature response (frequency deviation versus temperature) of a tuning fork crystal is described by the following formula:
Deviation [ppm] = -PC [ppm/°C^2] · (T-T$_0$)^2 ±10 %. In the coordinate system, this corresponds to a downward-opening parabola with vertex at T0 = 25 °C ±5 °C (reference temperature), as can be seen in Fig. 2. The factor PC (Parabolic Coefficient), here exemplarily -0.035, is provided in the data sheet and represents the measure for the "steepness" of the parabola. It is the most important parameter for the temperature behavior of the clock crystal. This parameter is also subject to tolerances, e.g. ±10 %.



Pic 2: The temperature response (frequency deviation over temperature) of a tuning fork quartz is described by the formula Deviation [ppm] = –PC [ppm/°C^2] · (T-T$_0$)^2, which is a parabola that opens downwards with a vertex at T$_0$ = + 25 °C ±5 °C (reference temperature).

IMPACT

It can be seen that the crystal always gives way as soon as it deviates from the reference temperature during operation, and the further it moves away from 25 °C, the more so. At +125 °C, this is typically -350 ppm in this case; when all tolerances (e.g., load capacitances) are included, it can be considerably more.

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 quartz with greater accuracy does not generally bring the desired success, since the specification of the basic accuracy refers 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 capacities or "averaging" of the temperature curve, is only promising in a narrow temperature range (e.g. wristwatch).

For applications that depend on a precise time base or require exact timing over a longer period of time (e.g. metering/consumption recording), it is essential to compensate the typical temperature curve by software and at the same time to synchronize the time at regular intervals with a master of whatever kind (data collector, radio clock, human). Only then a correct and reliable function of the application is guaranteed.

To determine the advantages of low load capacitance crystals, two clock crystals of 12.5 pF and 7 pF were compared. A 74HCU04 served as the oscillator IC, and advantages were found for the low load capacitance crystal as shown in Table 1.

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.

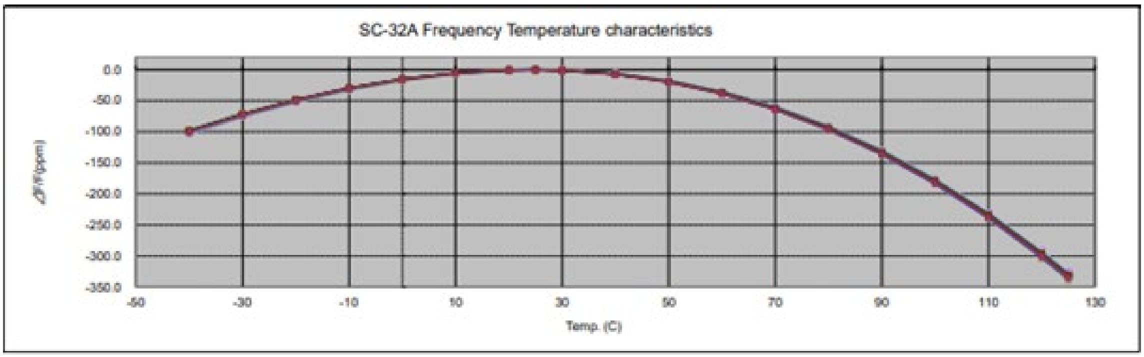
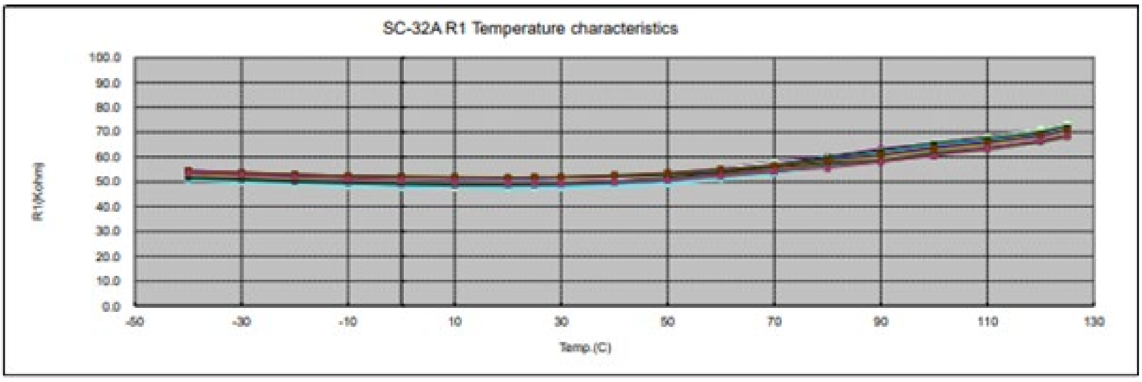


Figure 3 shows the temperature curve of a measured tuning fork crystal, with PC = (0.3 ±10 %) ppm/°C², where the described behavior becomes even clearer than in the theoretical curve.



From Fig. 4, one can see that the resonant resistance (ESR) increases slightly with increasing temperature, which makes the requirement for a tuning fork crystal with low ESR at extended temperature range very challenging.

TUNING FORK CRYSTALS WITH DIFFERENT LOAD CAPACITIES

To determine the advantages of low load capacitance crystals, two clock crystals of 12.5 pF and 7 pF were compared. A 74HCU04 served as the oscillator IC, and advantages were found for the low load capacitance crystal as shown in Table 1.

Test criterion	CL = 12,5 pF	CL = 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)

Note: The complete report can be viewed on the GEYER website.

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CHALLENGING APPLICATIONS AND TRENDS

The applications that are exposed to the largest and most frequent temperature fluctuations within a short period of time are found in the automotive sector. The corresponding components are specially manufactured with multiple contact points (attachment points) and AEC-Q200 certified so that they can withstand vibration and shock conditions. Geyer Electronic was quick to address the stringent requirements of the automotive industry and has been offering watch crystals for this market sector for years.

In addition, the trend in the industry is increasingly towards smaller packages for watch crystals, which poses another challenge for quartz performance (drive level) and resonant resistance.

While a smaller package size implies a smaller crystal power (drive level) and a higher resonant resistance, the temperature behavior does not change in the course of miniaturization. It still remains a technically demanding challenge for manufacturers and for users, because some applications require exactly the opposite. Thermostats with built-in radiators, solar inverters and similar product groups also require smaller tuning fork crystals with lower load resistance.

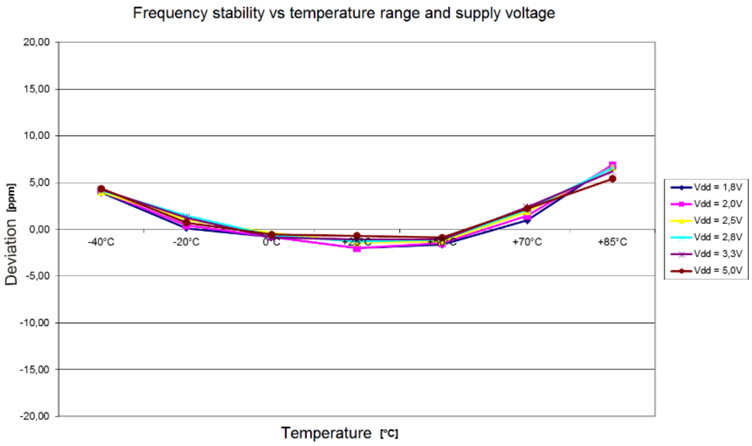
ALTERNATIVES TO TUNING FORK QUARTZ CRYSTALS

For higher temperature stability requirements, Geyer Electronic offers temperature compensated 32 kHz oscillators as an alternative, e.g. 20 or 10 ppm in the industrial temperature range in the KXO-V32T (3.2 mm × 1.5 mm) or KXO-V93T (1.6 mm × 1.2 mm) designs.

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

Typical values using the example of a KXO-V32T

It can be seen from Table 2 (here e.g. KXO-V32T) 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.



Frequency stability vs temperature range and supply voltage

CONCLUSION

In the last few years, during which the semiconductor sector has been subject to special challenges of various kinds and is only slowly recovering, the world has not stood still - the rapid development in the consumer goods sector, in the IoT and data world, and above all in the automotive industry have also pushed up the technical and logistical requirements for watch crystals. GEYER Electronic brought these new requirements into the production of crystals very early on.

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