

High-Stability Clocking for modern connected Devices

What makes a TCXO so special

In the first document of this series, we provided an overview of the different types of oscillators, touching briefly also on the TCXO and when to use this in electronic designs. In this document we will dig deeper into the role of TCXOs, keeping in mind the technical evolution and the commercial aspects.

A TCXO (Temperature- Compensated Crystal Oscillator) is used in applications where frequency stability and precision are mandatory even when the temperature changes. A correction voltage is generated by a temperature sensing and compensation circuit that is constantly used for frequency correction.

A typical TCXO temperature curve looks relatively flat, with only small variations, compared to an uncompensated crystal which follows a parabolic shape, both depicted in figure 1.

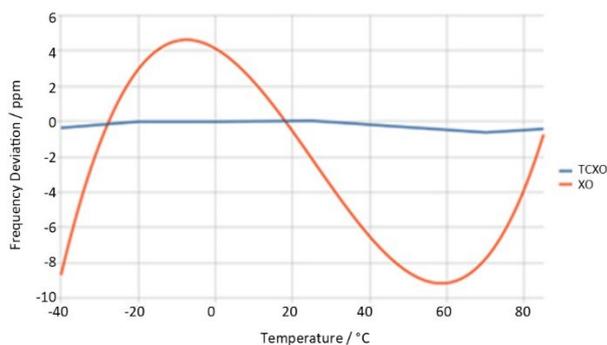


Figure 1: TCXO compensation curve over temperature

The temperature sensor measures the environmental temperature which is activating the compensation circuit, and adjusts the oscillator's frequency back to the nominal frequency.

Independent of the type of compensation mechanism – analog, digital, or hybrid – **this is the key to a TCXO.**

The role of TCXOs in electronic designs

The role of TCXOs increases as there are more and more applications in which developers consider using a precise oscillator rather than a crystal, accepting the obvious transitional cost increase.

Besides providing a reliable reference clock for digital circuits and RF systems, TCXOs offer much better stability than standard frequency components.

A standard crystal is designed for a typical 12-50 ppm frequency stability over temperature, while a normal XO oscillator has a frequency stability of about 20-50 ppm over the same industrial temperature range.

A TCXO can typically reduce the frequency drift to about 0.5-5 ppm, depending on the application needs. Only an OCXO (Oven-Controlled oscillator) can undercut that to 0.01 ppm, although with the disadvantage of much higher power consumption.

TCXOs are often used in

- **GPS receivers**, as they require very precise timing
- **Wireless communication systems** (LTE, Wi-Fi, Bluetooth)
- **High-precision instruments** (test and measurement)
- **Medical equipment** that requires precision
- **IoT devices** where temperature varies widely
- **Any type of digital system** where clock precision matters

Component Selection

A lot of articles and White Papers in the component industry focus on the definition and the function of a Temperature Compensated Crystal Oscillator (TCXO) providing use cases in which a TCXO fits better than a normal oscillator. However, there is little information about when a design is good enough using high precision crystals or when a TCXO fulfils better the application requirements.

Comparing the main technical aspects alongside cost, we summarized the results in the table below. The results are rather qualitative than quantitative as a thorough comparison makes sense only for a defined application with clear technical design goals. Even in that case, components are not necessarily chosen because they are the best but rather because they fulfil the scope with the right cost position.

Feature	Crystal (XTAL)	XO	TCXO	VCXO	OCXO
Component definition	Crystal quartz (w/o oscillator circuit)	Crystal quartz + oscillator circuit	XO + temperature compensation	XO with voltage tuning	XO in temperature controlled oven
Temperature Stability	15–100 ppm	20–100 ppm	0.5–2.5 ppm	similar to XO	0.001–0.01 ppm
Long-Term Accuracy	Low	Low	Medium–High	Low–Medium	Very High
Power Consumption	None	Low	Low–Medium	Low	High
Warm-up Time	None	None	None	None	Yes (1–5 min)
Cost	Lowest	Low	Medium	Medium	Highest
Size	Small	Small	Small	Small	Large
Stability vs Temperature	Good	Good	Very Good	Good	Excellent
Best For	Lowest cost-timing	General-purpose timing	Very -stable timing over temperature	Tunable clock needs	Ultra-stable frequency
Common Applications	MCUs Consumer electronics Simple digital circuits	Similar to Crystals	GPS/GNSS;LTE/5G /Wi-Fi /Bluetooth IoT/industrial devices Handheld radios Test equipment	PLLs & frequency synthesis Telecom Sync Jitter-cleaning Clock/data recovery	Frequency standards Base stations High-end test instruments Military/ aerospace Precision RF systems

Looking at the comparison above, one would conclude to consider OCXOs for applications where the frequency needs to be ultra-stable over temperature. While in the past this was the case, many designs no longer need ultra-stable raw oscillators because most of the systems handle stability in software or firmware. Thus, TCXOs are gaining more and more importance in electronic designs.

Although less common overall, OCXOs remain essential in applications that need ultra-stable frequency – but only if you can afford the power, size and the warm-up time.

What needs to be considered when selecting a TCXO? Where is the ‘Technical Break-Even’?

The importance of the TCXO in designs increases continuously, driven by applications with increasingly demanding requirements.

Summing up the results of our analysis in individual use-cases, we conclude as follows:

- TCXOs are essential wherever extremely precise timekeeping and signal synchronization are required as they best compensate for the temperature fluctuations.
- The choice between Quartz Crystal vs Oscillator/TCXO has to be taken case by case by the R&D developers based on the mid-term/long-term business case: application precision vs cost. **It is not a simple decision on component level.** A crystal will always remain the most cost-effective frequency component, but it will not alone form an oscillation circuit with the best accuracy over temperature.
- With precision still increasing, the production costs of TCXOs are dropping as volume is rising.
- TCXOs will soon become ‘commodity’ products.
- Unlike 5G networks and aviation for example, not every application requires extremely performant or special TCXOs

In the end there is no general “Technical Break-Even” for TCXOs. It is a deliberate technical choice acknowledging the cost increase of the product or service.

The sweet spot of a TCXO between performance, power and cost for regular applications would be:

Technical Parameter	TCXO
Frequency	10 MHz
Output Signal	Clipped sine
Output Amplitude	1.0 Vpp into 50 Ω
Frequency stability	1.0 ppm
Long-Term Accuracy	Medium–High
Power Consumption	Low–Medium
Phase noise @ 10 kHz offset	-140 dBc/Hz
Power consumption	15mW
Supply voltage	3.3V
Size	2.0x1.6 mm

Summary

While the evolution of defense industries, 5G networks and aerospace significantly drive the development of high-performance TCXOs over a wide temperature range, the automation sector, Smart environment, IoT applications and, increasingly, the healthcare sector are using more common TCXOs where the requirement of precision, miniaturization and low power consumption go hand in hand.

The TCXO is continuously evolving, providing reliable frequency stability across any environment.