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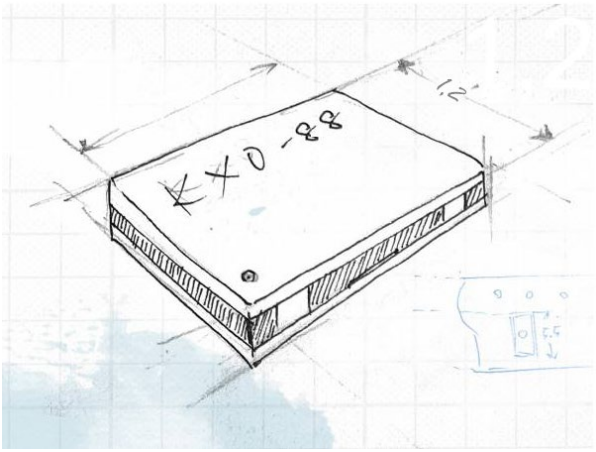
Crystal or TCXO Based Design - Where is the 'Technical Break-Even'?

For which application/specification range can a precise crystal quartz suffice and when is a TCXO necessary?

ABSTRACT

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

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 on the answer to the question: when is a design good enough using high precision crystals or when does a TCXO better fulfil the application requirements?



In this short paper we will focus on a few examples in which even a very precise, customized crystal will not suffice for the stringent requirements of the use case and call this the 'technical break-even' of a TCXO compared to crystals, even if the wording might not be completely accurate.

FUNDAMENTALS

A TCXO is an oscillator that integrates a quartz crystal with a temperature compensation circuit to minimize frequency drift due to temperature variation. The compensation circuit uses typically an analog or digital circuit to adjust the oscillator's output frequency based on temperature changes.

Key characteristics of TCXOs are:

- high frequency stability over a specified temperature range
- Low phase noise
- Different output types: Clipped Sine Wave, HCMOS
- Different voltage supplies
- Various SMD package types

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 25-50 ppm over the same industrial temperature range.
A TCXO can typically reduce the frequency drift to about 0.5-2 ppm, depending on the application needs.
An OCXO can undercut that to 0.01 ppm, although with the disadvantage of much higher power consumption.

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.

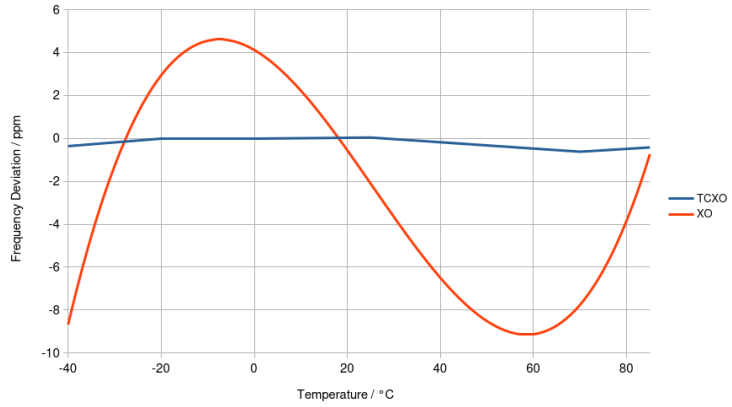


Figure 1: TCXO compensation curve over temperature

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 of a TCXO.

USE CASES for TCXO

Understanding the benefit of the temperature compensation, the question remains: at which point does a R&D developer decide to use a TCXO? The answer actually is quite simple: The TCXO is essential in applications requiring precise timekeeping and signal synchronization.

In these two cases, there is no other good solution than a TCXO based design, both from a technical standpoint as well as a cost perspective.

In a previous Whitepaper we had focused on the types of TCXOs and the most common applications using these parts.
The use case requirements are continuously changing, as technology also evolves.

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.

In the following examples of common use cases, we have analysed whether regular TCXOs can improve the behavior of the devices:

SMART Metering - TCXO or Crystal Based Design?

All smart meters, regardless of the type require:

- Wireless communication (mainly protocol independent)
- Precise time synchronization for accurate data analysis and reliable data transmission within the network
- Operation over a wide temperature range for usage in different environments
- Low power consumption to allow long life on battery power

Crystals fulfil perfectly these requirements, as they are:

- Communication-bus independent components
- Designed for an aging of ±10 ppm over 20 years
- Provide low tolerances of ±10-15 ppm over the entire industrial temperature range
- Have an overall lifetime tolerance of ±20 ppm to ±25 ppm
- Benefit from an excellent price/performance ratio.

So, why change the design to a TCXO?

Low power consumption to extend battery life in remote and off-grid meters and improved reliability in outdoor environments with significant temperature variations are just two reasons that justify the use of a TCXO. Looking at a typical frequency of 32 MHz, for a 10-fold improvement in tolerance over the temperature range, when switching from a crystal to a TCXO you can expect to pay around 3-4 times the price of a quartz at the start.

This might sound a lot considering the price-sensitivity of the market. However, the calculation is not really accurate – one has to consider the R&D and component costs that have to be spent to provide a similar stability using a common crystal. In addition, prices of TCXOs are decreasing due to production volume increases.

Environmental Monitoring and Smart Cities – TCXOs' role in sustainability

Crystal oscillators are used in environmental monitoring applications and smart city infrastructure, where IoT devices play a vital role in improving the quality of life and sustainability.

Weather stations, air quality monitoring, and agricultural IoT sensors are just some examples using IoT devices that monitor air pollution, water quality, and other environmental factors requiring precise time-stamping for accurate data collection and reporting. TCXOs and VCTCXOs help maintain the precision needed for long-term environmental data monitoring.

While low power consumption and precise time stamping can also be reached with quartz crystals, the synchronization of the data over a wireless protocol, like LoRa, Zigbee, NB-IoT, etc, together with precise monitoring in each weather condition, can only be reached using components that keep the temperature drift low.

IoT and Low Power Devices – TCXO contributions to energy efficiency

TCXOs offer a good balance between stability, low power and cost efficiency and are thus an optimal choice for IoT devices which are often battery-operated and have energy efficiency as one of their top priorities.

Power efficient IoT systems, such as sensors for example, make use of the so-called sleep mode, meaning that they operate intermittently, waking up to take measurements and then returning to a low-power sleep mode. TCXOs are used in sensors, industrial monitoring, remote environmental sensing and more, to maintain accurate timing while consuming very little power during sleep periods. They work in conjunction with low-power microcontrollers, forming a couple of components which contribute to the energy efficiency of the device, extending battery life-time while balancing performance and power consumption.

Many IoT devices, such as wearables or environmental sensors, require continuous monitoring and recording of data. TCXOs help maintain accurate timestamps for the data collected, ensuring reliable time-based analysis.

Ultra-low power SoCs (system on a chip) match perfectly with small crystals in the 2.0x1.6mm package size. They can also work with a TCXO in that package size, adding the benefit of high frequency stability over a wide temperature range while maintaining synchronization and reducing packet loss.

HealthCare and Medical Devices – improving reliability by using a TCXO

The healthcare branch is one of the industries that is very wide fold, while having extremely high technical requirements.

The continuous evolution of medical equipment in recent years has imposed changes in the selection of the electrical components used in the manufacturing of the devices. More and more use TCXOs as their performance ensures the reliability of various equipment, for example:

- Patient Monitoring Systems
- MRI and CT Scanners
- Ultrasound machines
- Hearing Aids and Implants
- Medical IOT Sensors
- Wearable Health Devices

Medical equipment, although often used in controlled environments such as hospitals or doctors' surgeries, can still be exposed to temperature fluctuations. So, tight frequency stability of 0.5 -1 ppm is of use.

Low phase noise and stable frequency ensure a proper wireless connectivity and prevent signal loss or interference with other equipment.

All imaging procedures (ultrasound, MRI, X-ray, etc.) require high precision components to obtain high-resolution, high-contrast and sharp images even in climatically varying environments.

Monitoring and life-support systems, e.g. in intensive care medicine, need to ensure absolutely safe operation even under problematic conditions.

Automotive and Autonomous vehicles – TCXO - a must for safety

The automotive industry has always been very demanding in terms of precision as even the smallest deviation from the intended functionality can impact human safety and application reliability. With the evolution to autonomous driving, the accuracy in timing and frequency control becomes even more important and safety requirements more stringent. Dynamic detection of the 'environment' of an autonomous vehicle (cameras, radar, LIDAR, etc.), must function reliably and safely even under the most adverse conditions.

For electric cars energy management, charging process, battery management, and correct billing must work under every weather condition.

Quartz Crystals and standard oscillators have been serving and will continue to serve the purpose of this industry very well. They are small, reliable and are specifically manufactured and tested for the Automotive industry required certification.

TCXOs add another level of accuracy by keeping temperature drifts low in every climatic change condition while adding additional precision to the automotive applications.

TCXOs, as well as all other frequency components used in the automotive industry, require special AEC-Q certifications.

OUR PRODUCTS FOR TCXO based designs

As a design partner for its customers and as a long-standing component manufacturer, GEYER Quartz Technology embraces the latest industry trends keeping the flexibility in design and manufacturing.
We offer a wide range of oscillators. Depending on the application, we supply oscillators of the types PXO/XO/SSO, VCXO/LVDS/PECL, TCXO/VCTCXO, from our product portfolio and also to customer-specific requests.
Continuous technical improvements on technical parameters such as phase noise and stability, along with production cost reduction, qualifies us in customer designs using the latest generation TCXOs.

As emphasized by some of our use-case examples, the GEYER TCXO product family, overviewed in Table 1 below, can be used in high precision applications such as IOT, Smart Environment, Healthcare, and many more sectors.

	KXO-83	KXO-84	KXO-86	KXO-81	KXO-88
Case type	5.0x3.2 mm	3.2x2.5 mm	2.5x2.0 mm	2.0x1.6 mm	1.6x1.2 mm
Oscillator Output	HCMOS Clipped Sinewave	HCMOS Clipped Sinewave	HCMOS Clipped Sinewave	HCMOS Clipped Sinewave	Clipped Sinewave
Frequency range	6.0–40.0 MHz	8.0–70.0 MHz	13.0-56.0 MHz	9.5-60.0 MHz	13.0-52.0 MHz
Frequency stability (typ.)	±0.5 ~ 2.5 ppm @-40°~+85°C (depending on type)				

Table 1: GEYER Electronic TCXOs

Reliable signal transmission, excellent frequency accuracy and low jitter are just some of the parameters offered by our TCXO family. The list of the major parameters can be found on the GEYER Electronic oscillator product page: https://www.geyer-electronic.de/en/products/oscillators/#32b260b7a45f0b4f9

Our Webshop supports you in selecting the product that best fits your needs from performance and price point of view. For demanding applications, we manufacture customized components, tailored to your use-case requirements and life-time.

Based on the market evolution we offer specialized Development Kits and Reference Designs for the combination of your IC/SoC and the TCXO of your choice. In our R&D lab, alongside consultation for choosing the best component for your design, we optimize your oscillator circuit to the specific requirements of your application.

CONCLUSION

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

To sum up the results of our analysis in individual use-cases, the conclusions are as follows:

- TCXOs are essential wherever extremely precise timekeeping and signal synchronization are required as they best compensate 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.

For technical consultation, design support and quotes with TCXO, and other components, just contact us via our Website, Webshop or via e-mail.

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