New Generation of TCXO's Equals Accuracy and Precision of OCXO's

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Quartz crystal resonators have been used for many years as the frequency reference for radios and other communication devices. When exceptional precision was needed, the crystal was placed in an oven that held the crystal at a constant temperature – hence the term Oven Controlled Crystal (XTAL) Oscillator or OCXO. The OCXO has long represented the greatest precision that can be obtained from a quartz crystal based frequency reference.

Although OCXO's offer the greatest precision, there are several considerations that limit how they can be applied to many system requirements. These include:

- Demand power to heat the oven, with internal temperature in the 75°C to 95°C range;
- Significant time from turn-on for the OCXO to warm-up and stabilize in frequency;
- Relatively long time to reach the precision frequency; and
- Larger package size, needed to have insulation around the ovenized portion.

To avoid many of these OCXO limitations, the Temperature Compensated Crystal Oscillator or TCXO was developed. In this case, circuitry was added around the crystal

resonant element to correct or pull the crystal to a stable frequency versus temperature. The TCXO capabilities were typically not quite as precise or accurate as the OCXO, but since TCXO's operated at much lower power and could be smaller in size, they satisfied much of the market's demand.

The demand for TCXOs greatly increased with the development of the personal portable phone, the cell phone, and Handy Phone, etc. Because of stability requirements, battery operation and size requirements, the TCXO was the ideal solution. Figure 1 shows a TCXO typical of the early 1990's, the large amount of circuitry needed for compensation is seen in the bottom view of the TCXO. This type of TCXO was capable of ±2.5ppm over the operating temperature range. The internal circuits needed to be calibrated or matched to each individual crystal.

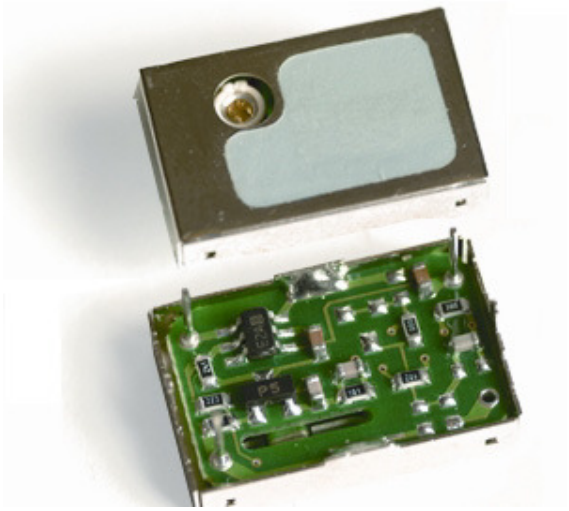


Figure 1. Typical TCXO of the early 1990's.

Making TCXO's Easier to Produce

To make the TCXO easier to produce, integrated circuits were developed to make the compensation process easier and the resulting circuit smaller. For example, in the late 1990s, Philips and KVG-Vectron both developed custom analog circuits that had external resistors that were laser trimmed to perform the compensation with built in varactor diodes to pull the crystal frequency.

Driven by demand for large number of TCXOs, and as analog IC processes began to permit ROMs to be included, new TCXO designs were being developed. Stored in the ROM values were the needed settings so the analog circuits would provide the correction voltages to the crystal oscillator circuit. ROMs that were programmable appeared, and CMAC (later Rakon by acquisition) and Panasonic used fusible links, Micro Analog Systems (MAS) used ePROM, and Asahi Kasei Corp. (AKM) used eePROM to name some of the more prominent. These programmable ROMs simplified the compensation process, made for smaller TCXO's, and in most cases required less power.

Photo: 1990's Cell Phone TCXO (tcxo.old.jpg)

In the late1990's there was also increasing demand for performance to be better than the cell phone ±2.5ppm. The emerging public demand for GPS devices provided the large market and a demand to reach ±0.5ppm. The crystal part of the TCXO had to be improved, and a number of advances were made, including:

- Development of the AT cut crystal strip resonator
- Availability of the ceramic leadless chip carrier (CLCC) package (smaller size, hermetic, well controlled mounting points for the quartz crystal resonator)
- Improved crystal mounting cements
- Changes in the crystal mounting
- Improved package sealing methods

Figure 2 shows how much improvement was accomplished over the seven year period from typical designs in 2002 to those of 2009.

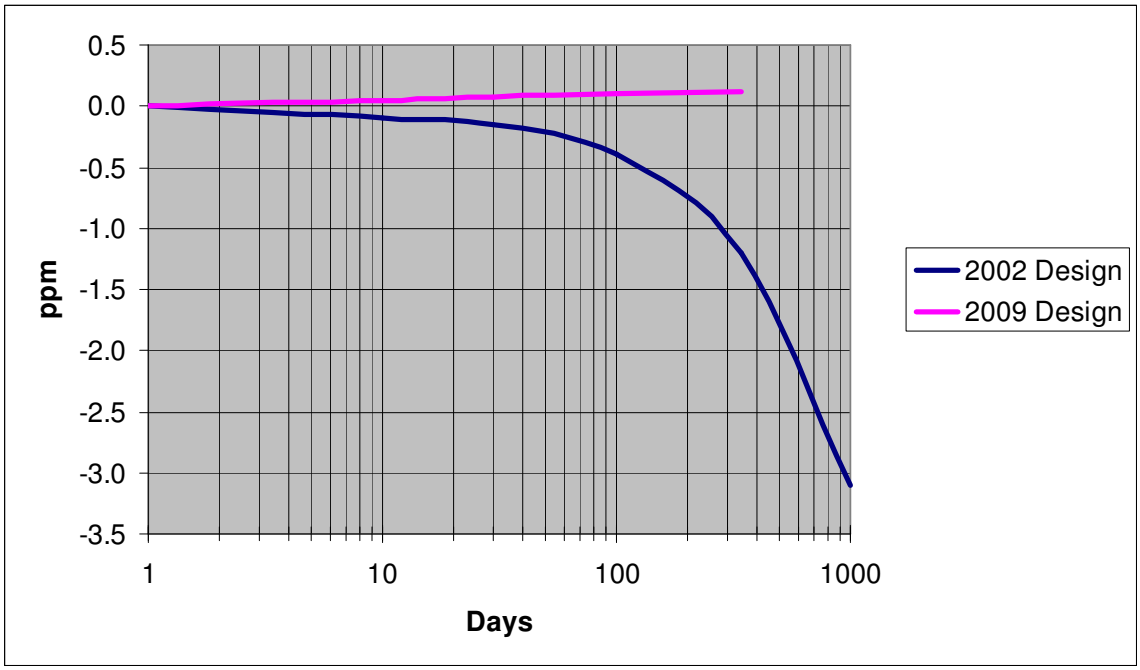


Figure 2: **Aging at 77° C. Improvements in performance of the SMD crystal design and fabrication.**

The cell phone industry has made a number of other demands on the frequency control industry. With the user desire for more data, the bandwidths needed required new modulations schemes, improved bit error rates, and improved signal levels. The need to penetrate buildings with error free signal levels posed new challenges. These needs can be met with personal cell sites, which many call Femtocells, or miniature cell towers. This is a small unit placed in the office or home that has all the performance features of a cell tower and thus requires a frequency reference that combines simplicity and low power but can also rival the stability and accuracy of OCXO's that are used in cell tower systems.

These new TCXOs with Electronic Frequency Control (EFC) have holdover capabilities of ±0.10 ppm for 24 hours over the operating temperature range. Therefore, using a time base correction that can be derived over the internet (IEEE 1588) or GPS, frequency precision of ±0.10 ppm can be achieved long term. These are performance requirements unheard of before – needed to meet the demands of a potential market that is exceptionally large. With collaboration between the IC industry and the quartz crystal industry, there are now TCXOs that meet or exceed the FemtoCell requirements.

Companies like AKM, MAS and Rakon have developed TCXO ICs with the fine control and stability to meet these needs. The quartz industry has also kept pace with continued improvements in the performance of the crystal mounted in the CLCC package. Figure 3

shows the aging performance improvement that is being achieved compared to a low cost ceramic packaged crystal made today.

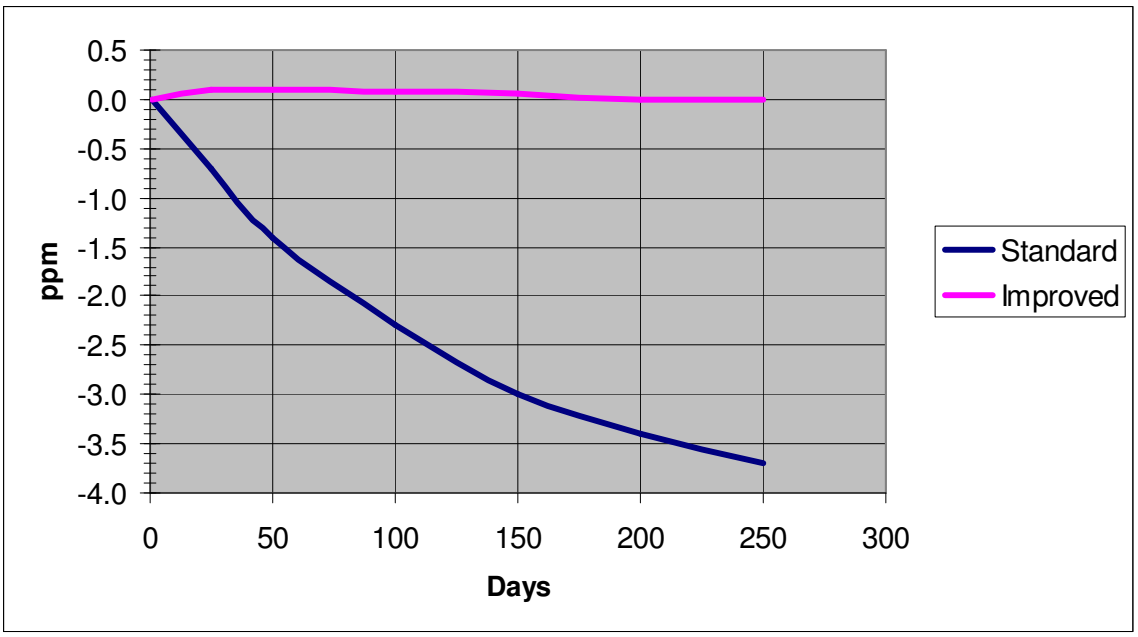


Figure 3: Aging at 85°C. Comparing a typical SMD crystal's aging to the improved TCXO's used for the OCXO equivalent (Pletronics O*e*XO™ Series).

The increased accuracy and stability of these new TCXO's is accomplished by:

- The precision manufacturing of the resonator element
- The crystal portion of the TCXO is in its own sealed space
- Decreased package size, which helps with thermal stability and aging
- The use of chrome-gold instead of the lower cost nickel-silver for the crystal electrodes
- Improved electrode deposition
- Final frequency adjustment with ion milling of the electrode thickness

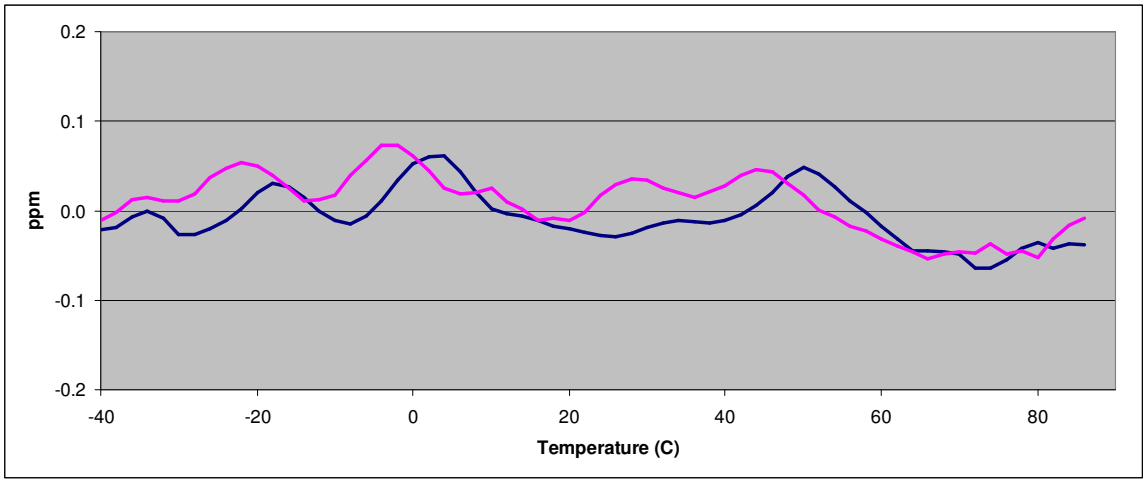
- Stress free CLCC package sealing

These improvements enable the newly developed TCXOs to now perform as well as many of the smaller packaged OCXOs. In addition to several other suppliers, Pletronics has developed TCXOs that not only meet the accuracy and stability of OCXOs, but also offer the following advantages.

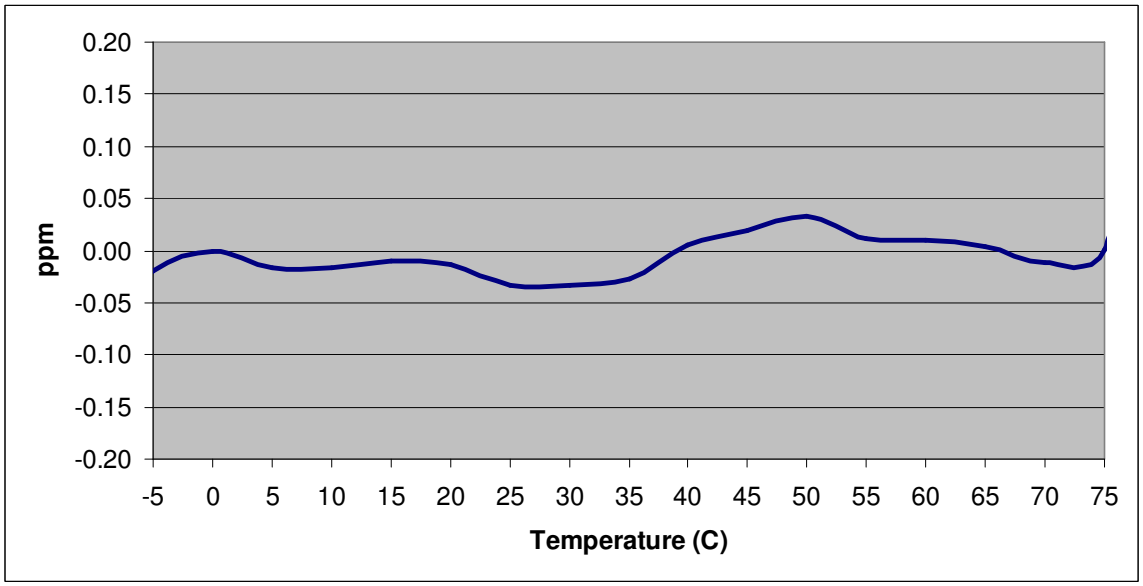
- Exceptionally lower power, typically 34 times less power required at -20°C
- No turn-on/ surge warm-up current needed
- Dramatically reduced need for system power supply capacity
- Nearly instant full performance when turned on compared to 2 or more minutes for the OCXO
- Repeated On/Off power cycling required in remote satellite communication applications does cause the shortened life which hampers OCXOs
- HCMOS or clipped sine wave (low EMI/RFI properties) output
- Smaller sizes available
- Frequency range from 10MHz to 52MHz.

Devices tested: Pletronics OHM4, DIP/DIL OCXO, and Pletronics OeXO Series OeA4

Typical New TCXO Design, Performance versus Temperature



Pletronics OeD4 device operated -0° C to 85° C. Showing hot-to-cold and cold-to-hot temperature changes.



Typical performance of OCXO equivalent in 0°C to 70° C range

Conclusions

Market demands for more stable and accurate frequency signal generators have led rapid advances in ICs, in quartz crystal science and manufacturing, and in SMD packaging. On-going development of hand-held products and wireless applications will continue to spur improvements in quartz crystal technology and lead to clock generators of even greater accuracy and precision.

Note: Founded in 1979, Pletronics, Inc. manufactures a wide range of crystals and oscillators, specializing in precision TCXOs, OCXOs, and high frequency PECL, LVDS and CMOS oscillators. Send questions or comments to engineeringgrp@pletronics.com or call 425-776-1880.

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