Understanding TCXOs

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Temperature Compensated Crystal Oscillators (TCXOs) are widely used in today's wireless communications systems. They have become a vital component to cell phones and the growing wireless PDA industry. High-end TCXOs are also an important component in telecom and other industries.

The major difference between a TCXO and a simple crystal oscillator is that the TCXO contains additional circuitry that corrects (compensates) the crystal's frequency vs. temperature characteristics. **Figure 1** depicts a simple illustration on how the crystal is corrected. The additional compensating circuitry falls into three major categories: Digital, Analog or Analog/Digital combination. Understanding the differences between digital and analog compensation is important since they, in some cases, are not interchangeable.

The un-compensated frequency stability shown in **Figure 1** is of a typical AT-cut quartz crystal. It is actually a family of curves determined primarily by the angle at which the crystal blank is cut. These curves follow a cubic equation of the form:

$$\frac{\Delta f}{f} = a(t-t_0) + b(t-t_0)^2 + c(t-t_0)^3 \quad (ppm)$$

Where: t = actual temperature

$t_0 = 26^\circ C$

a, b and c are the Bechmann's coefficients

Commodity TCXOs are available from +/-1.5ppm to +/-5ppm frequency stability over -40ºC to +85ºC, with the most standard spec being +/-2.5ppm over -30ºC to +75ºC. Frequency stabilities below +/-1.5 ppm over 0ºC to +70ºC are difficult to achieve and hence fall into the high-performance category. Commodity TCXOs typically cost less than $8, while high-performance TCXOs are often $15 or more.

Commodity TCXOs can be manufactured in very small packages, such as 5x3.2x1.5mm and even 3.2x2.5x1mm with smaller sizes on the horizon. These tiny oscillators are all ASIC-based for high-volume manufacturing. Due to the specific ASIC being used, the crystal oscillator companies cannot offer any customization except for frequency within the range of the family. In addition, all these small TCXOs are actually VCTCXOs – that is, they provide a pin for electrical tuning or deviation.

Output waveform options on these tiny TCXOs are limited to clipped-sine or sinewave only. If you need HCMOS, for example, it is available only on the larger packages. High performance TCXOs are available with all the popular waveform options (Sinewave, HCMOS, LVPECL, etc.). The clipped-sine waveform has one major advantage over the other waveforms: current draw. The typical current draw for clipped-sine is 2mA max at +3V. The internal clipped-sine driver is simply sourced from the collector of a bipolar transistor. This means that load seen by the oscillator has to be high impedance; typically it calls for a 10K Ohm load. The clipped-sine driver is perfect for driving PLL ICs directly providing a low current solution.

There are four digitally implemented (and one basic analog) types. These are as follows:

- TCXO – Temperature Compensated Crystal Oscillator (See **Figure 2**)
- ADTCXO – Analog Digital Temperature Compensated Crystal Oscillator (See **Figure 3** with the exception that the DAC and Logic are replaced with a Cubic function and analog amplifiers respectively)
- DTCXO – Digital Temperature Compensated Crystal Oscillator (See **Figure 3**)
- MCXO – Microprocessor Compensated Crystal Oscillator (See **Figure 4**)
- DCXO – Digitally Controlled Crystal Oscillator

The ADTCXO in **Figure 3** is the type now used in the cell phone industry and is available in 5x3.2x1.5mm and smaller. These oscillators are also being designed in all types of equipment due to their small size and low cost. But, designers beware: with the DTCXO version of **Figure 3** and the other digital implementations, phase hits (abrupt phase changes) will occur when the oscillator makes a correction because it sensed a temperature change. The ADTCXO version of **Figure 3** does not have phase jumps due to its analog back-end.

Determining if an oscillator has phase hits or frequency steps may not be easy to see in the frequency vs. temperature curve. Taking the first derivative of the frequency vs. temperature data can help reveal the phase hits. Another way to see the phase hits is to set up a test with the TCXO being used as the reference frequency to a phase locked loop (PLL), then monitor the error voltage on phase detector while the TCXO is ramped over temperature.

A large phase hit can un-lock many communication links if it cannot be absorbed. Therefore, due diligence must be done upfront by the designer considering using a digitally implemented oscillator.

The Digitally Controlled Crystal Oscillator (DCXO) is not shown here as a block because it can be implemented in many different ways. The author defines a DCXO as any crystal oscillator where the frequency of the crystal is corrected by the equipment's host microprocessor. The correction intelligence may be the following:

1) Crystal's freq. vs. temp. curve
2) Timing from an external source (i.e., a cell station can pass timing to the PDA or cell phone)
3) Reference frequency from an external or internal source

The designer of a DCXO may not want to achieve the stability of a good TCXO. For example he or she might be satisfied with compensating/correcting a +/-25ppm crystal to +/-5ppm without adding the cost of a standalone TCXO. Another advantage to using the host microprocessor to perform corrections is that one can halt the update when transmitting, and possibly while receiving.

Table 1 summarizes the different versions of the TCXOs as well as simple clocks (XO) and VCXOs for comparison.

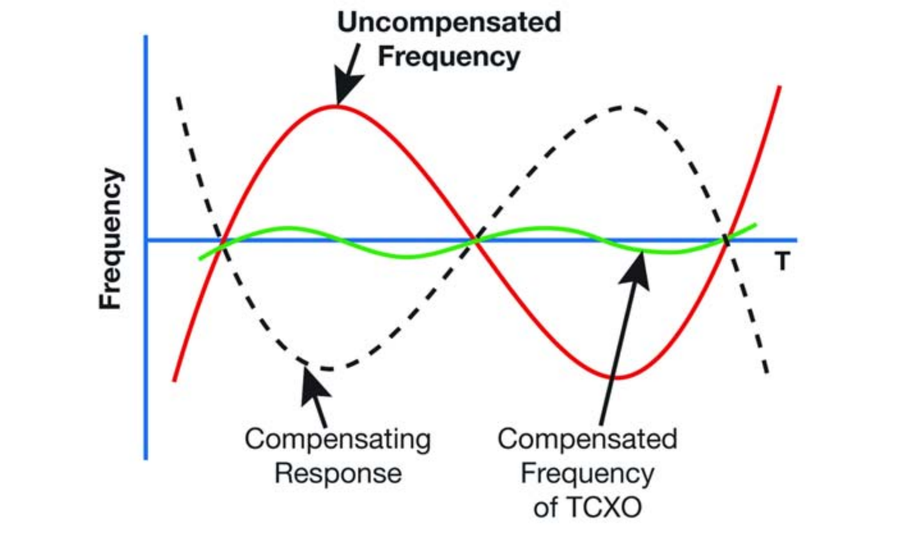

Figure 1: TCXO Compensation

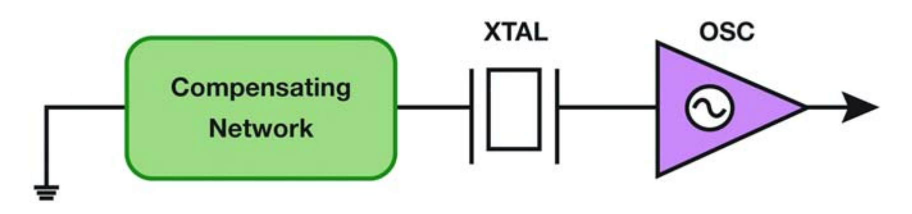

Figure 2: Analog TCXO

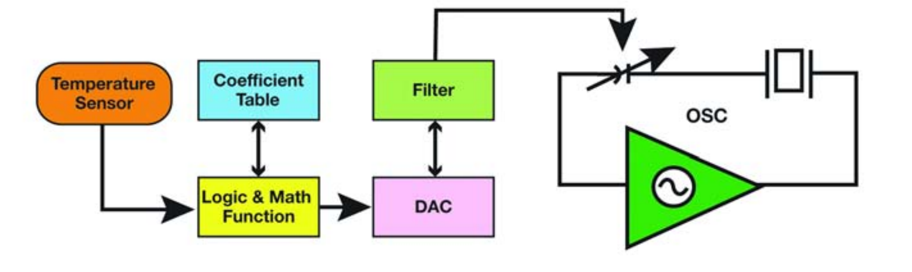

Figure 3: Digital Temp. Comp. Crystal Osc. (DTCXO)

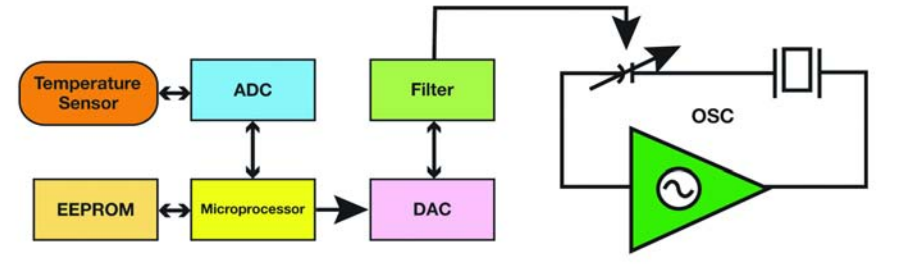

Figure 4: Microprocessor Compensated Crystal Osc. (MCXO)

Osc. Type	Freq VS Temp 0º to 70ºC (± ppm)	Temp Sensor	µP	Price Range
XO	10 to 100	No	No	Lowest
VCXO	10 to 100	No	No	Low
TCXO	0.1 to 5	Yes	No	Medium
DTCXO/ ADTCXO	1 to 5	Yes	No	Low
DCXO	0.05 to 5	Yes and No	Yes (in host eqpt)	Low
MCXO	0.05 to 1	Yes	Yes	Highest

Table 1: Oscillator Type Comparison of Stability and Price Range

Reference

John R. Vig, "Quartz Crystal Resonators and Oscillators"

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