What is an OCXO?

White Paper

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WHAT IS AN OCXO?

The term OCXO is an acronym for Oven Controlled Crystal (Xtal) Oscillator. The OCXO is a quartz-based timing device (clock) utilized in precision timing applications. When stability and accuracy requirements exceed the capabilities of other quartz-based frequency control devices such as a XO (clock oscillator), a VCXO (voltage controlled crystal oscillator), or a TCXO (temperature compensated crystal oscillator), an OCXO is called upon to provide the necessary performance. OCXOs bridge the stability gap between a TCXO and atomic clocks and are the highest performing members of the quartz-based class of oscillators. This article will discuss the operation of OCXOs, the highest stability quartz-based timing device, and help gain insight to their operation.

APPLICATIONS

For many applications and system configurations, local clocking capabilities require timing redundancy to provide back-up in case of loss of the timing reference. Local timing devices located within network system elements are designed to operate in both lock mode (locked to GPS or network reference) and holdover mode (loss of lock). They are there to maintain system accuracy and low drift rates when the system becomes unlocked.

Applications steered by GPS such as ocean bottom seismic nodal, military data links, or certain test equipment use local oscillators as a backup to GPS. As quartz-based timing devices are well-known for their performance attributes such as; high Q, long-term accuracy, and high stability, these devices are well suited as a clocking backup.

OCXO PERFORMANCE GRADE

OCXOs are within the middle ground of the frequency stability spectrum. Figure 1 illustrates the hierarchical relationship of relative stability (and cost) between different frequency control devices. Most atomic clocks typically utilize an OCXO for their output since the high Q of an OCXOs quartz resonator provides superior short term stability and noise performance. For applications that require a lower level of performance than an OCXO, a TCXO, or even an uncompensated XO may suffice. Although the OCXO sits at the pinnacle of performance in the quartz crystal based frequency control family, for higher performing frequency sources, one must turn to atomic clocks.

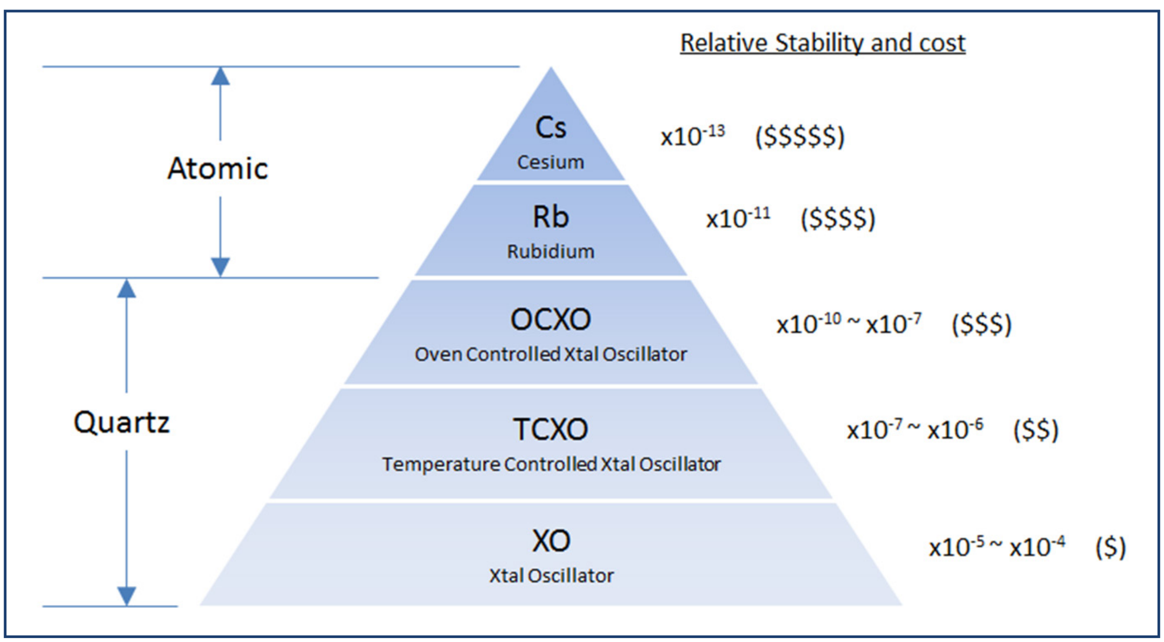


Figure 1: Hiearchy of Frequency Control Device Accuracy and Relative Cost

HOW OCXO'S WORK

As its name implies, an OCXO utilizes an internal oven whose temperature is very tightly controlled. Housed within this internal oven is a hermetically sealed quartz resonator and its peripheral oscillator circuitry. By taking advantage of a quartz crystals frequency vs temperature characteristic, the OCXO can achieve excellent stability performance. The tight thermal control of the crystal and oscillator circuitry greatly minimizes the effects of variation in the surrounding ambient temperature. A well-designed oven will hold the crystal temperature to less than 1°C of variation over an external ambient temperature range of -40 to +85°C.

The oven in an OCXO is preset to a temperature that corresponds to a particular crystals "ideal" temperature. This ideal temperature is commonly called the crystals "turn-over" temperature, or turning point (TP). The TP is the zero slope point of a crystals frequency versus temperature characteristic curve.

There are many different crystal cuts that can be manufactured from a quartz bar, all having different characteristics and attributes. The most common crystal used in quartz-based oscillators is the AT cut. Figure 2 is a depiction of the FvT curve of an AT cut crystal and highlights the difference in temperature stability (dF/dT) when operated both on and off of the crystals TP. Notice there are actually two turning points on an AT cut crystal; an upper (UTP) and lower (LTP). For the case of an OCXO utilizing an AT cut crystal, only the UTP matters as the LTP occurs well below 25°C.

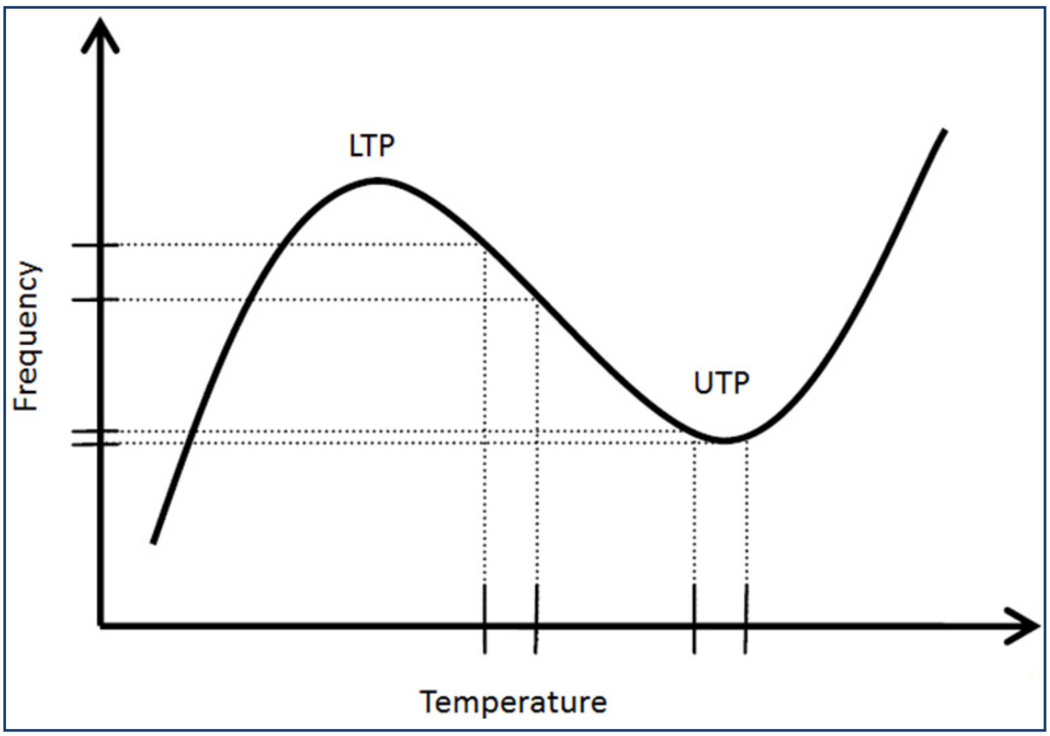


Figure 2: dF/dT Curve of an AT Cut Crystal.

Figure 2 provides an illustration of how the dF/dT response of a crystal can be minimized by careful selection of the oven set temperature. This is the crux of how an OCXO achieves its frequency stability.

Although AT cut crystals are the most commonly used in OCXOs, SC and/or IT crystals may be used to achieve even higher precision. These cuts are part of the family of doubly rotated variants. An AT crystal is cut from a quartz bar rotated in just one of three crystallographic axes while the SC and IT crystals are simultaneously rotated in two of the axes when cut. These doubly rotated crystals offer better noise performance (higher Q values), aging, temperature stability (dF/dT), lower sensitivity to oscillator circuit instabilities, and are inherently stress compensated (less susceptible to thermal and mechanical stresses). Figure 3 graphically illustrates the advantage of a doubly rotated SC cut crystal versus an AT.

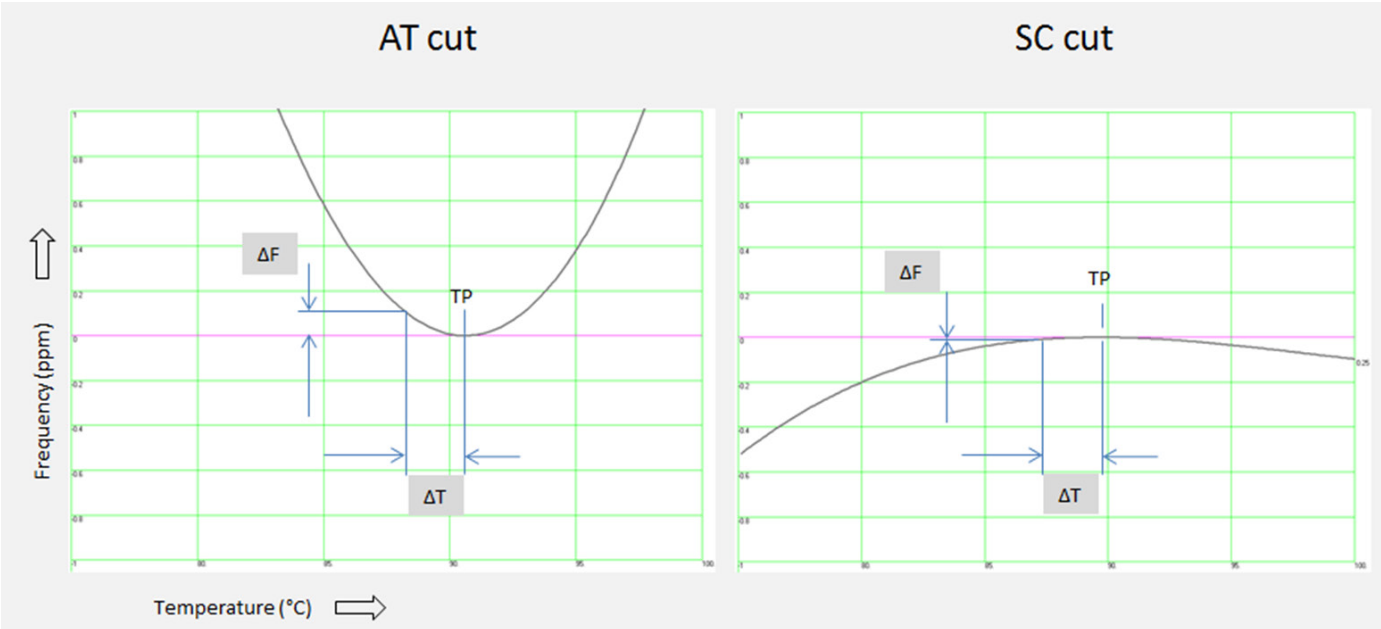


Figure 3: Illustration of dF/dT of an AT Cut versus an SC Cut Crystal on Turning-Point

It can be seen in Figure 3 that at the crystals turning-point, an SC cut crystal is much flatter or broader than an AT cut. Therefore an SC will react with significantly less freq change (better stability) due to temperature variation than an AT cut.

TEMPERATURE CONTROL

The temperature stability of an OCXO is derived from the ability of an oscillator manufacturer to set and control the internal oven to a precise temperature that corresponds to a crystals TP. The temperature control is achieved with the implementation of a proportional control oven circuit. The proportional oven controller is an electronic control system that provides continuous oven power, see Figure 4. The amount of power supplied varies inversely with ambient temperature.

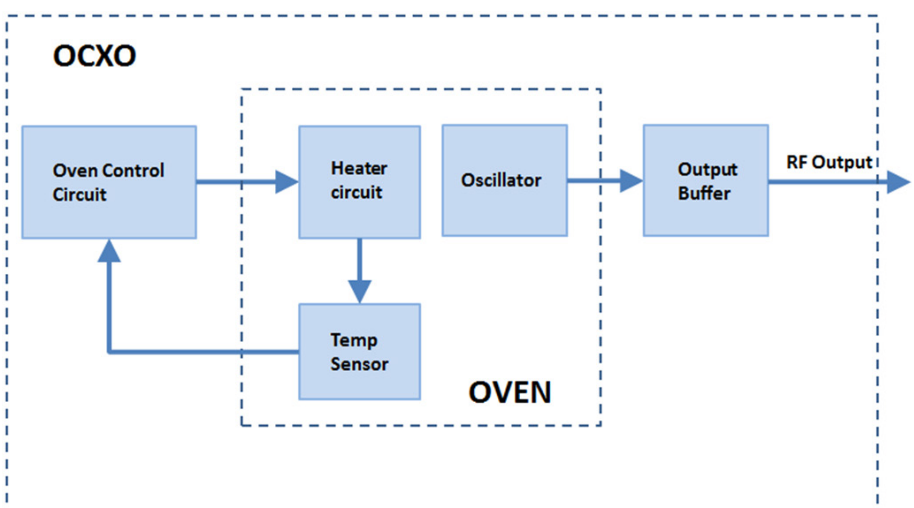


Figure 4: Proportional Oven Controller Block Diagram

In a proportional control oven, when a temperature change is sensed by a thermistor (or other temperature sensing device), an error voltage is produced. This error voltage is fed back to a bridge network in the control circuit forcing it to either supply more power or to throttle back the power being delivered to the oven.

The conventional method of controlling temperature utilizes a thermostatic control mechanism whereby the heating source cycles on/off with a period relative to the ambient temperature. Examples of this heating method would be the furnace in ones' home or a typical kitchen oven. Figure 5 illustrates power consumption and resulting frequency stability of an OCXO with proportional oven control versus thermostatic control.

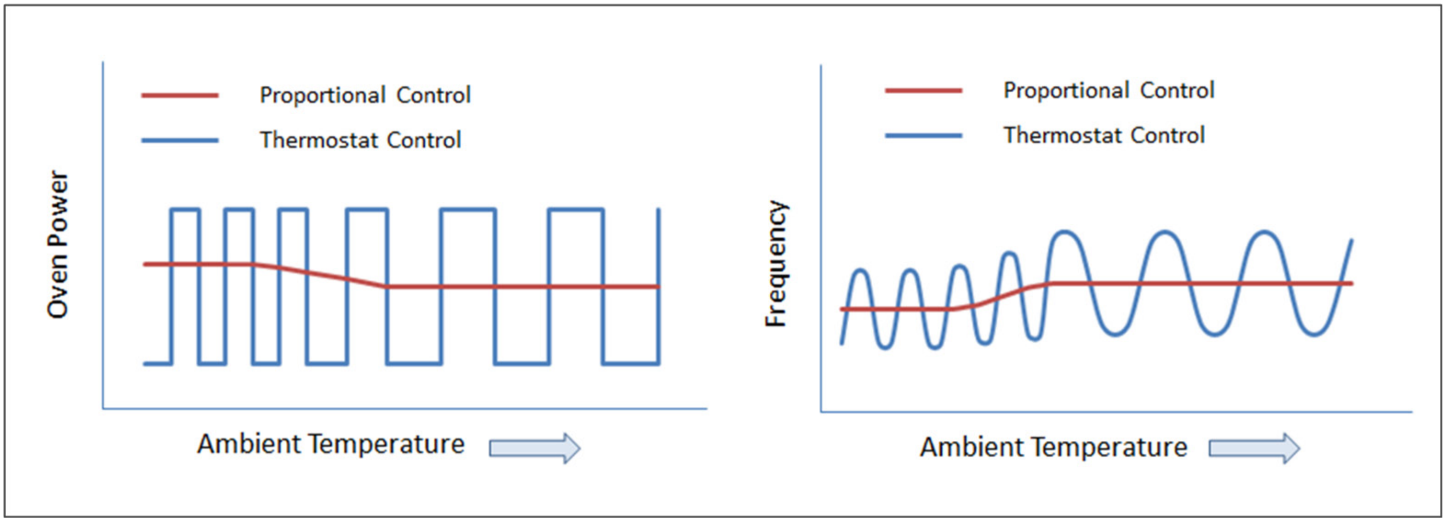


Figure 5: Oven Power and Frequency Response for Proportional vs. Thermostatic Oven Control

Although the average frequency deviation due to temperature change may be consistent between the two heating methods, proportional control is a far superior method to achieve the stability levels required by an OCXO.

WARM-UP

When an OCXO is initially powered on, it will take time to reach its specified final frequency. When powered on at 25°C, an SC cut crystal will be approximately 20 ppm below its final specified frequency where an AT cut is perhaps 60 ppm above. Figure 6 compares the warm-up characteristic of an SC crystal versus an AT.

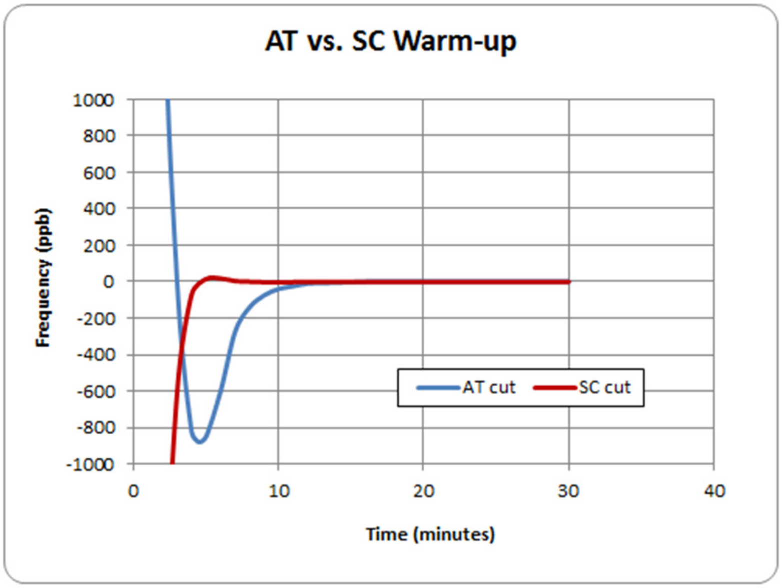


Figure 6: AT Cut versus SC Cut Characteristic Warm-up Curve

The negative overshoot and comparatively slow stabilization of the AT cut crystal is an artifact of the thermal and mechanical stresses within a singly rotated crystal. The overshoot is induced by a sudden power-on and the high rate of temperature change of the oven. The SC cut crystal does not exhibit the same level of transient response as the AT due to the lack of stress sensitivity inherent within the doubly rotated crystal.

POWER CONSUMPTION

A trade-off design engineers must consider when choosing an OCXO versus other frequency control devices, is power consumption. Due to its internal oven, standard OCXOs are power hungry devices when compared to XOs, VCXOs, or TCXOs. Typical OCXOs may require anywhere from 2 to 4 watts of power during the initial warm-up period but will reduce to perhaps 0.7 to 1.5 watts when stabilized at +25°C (TCXOs in the 10 to 100 milliwatt range). Fortunately, CTS offers a low-power consumption class of OCXO that consumes significantly less power than a typical OCXO. These Low Power OCXOs (LPOCXO) typically draw <0.15 watt at +25°C while still offering exceptional temperature stability, aging, and noise performance.

As previously mentioned, oven power is inversely proportional to ambient temperature. As ambient temperature decreases the oven requires more power to maintain its set temperature. Likewise oven power decreases as ambient temperature increases. There are several factors that affect the power consumption of an OCXO such as; the size of the oven (smaller is better), the set temperature of the oven (crystal TP), and the amount of thermal insulation within. A system design engineer can help to reduce power consumption by positioning the device away from the direct airflow of a cooling fan, or even shielding it within the system. It is not advisable to completely cover (shield) an OCXO as its internal heating, coupled with the external ambient heat rise within an enclosed structure, may cause the oven to lose control or to completely shut-off. For this occurrence the crystal will to drift freely with the external temperature at the expense of frequency stability.

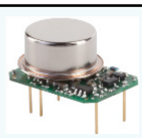
CONCLUSION

Multiple industry segments have specific requirements and applications that rely upon highly accurate and stable timing devices to achieve their specified performance. These industries include for example, off-shore gas and oil exploration, commercial airborne broadband, military communications, mobile test equipment, high definition imaging and satellite datalinks. Many of these applications are operated under severe environmental conditions requiring ruggedized mechanical construction and/or extreme ambient temperatures. Other cases may be battery powered but still require the stability and noise performance of an OCXO.

CTS SOLUTIONS

CTS offers a complete line of high performance oven controlled crystal oscillators available in a broad range of frequencies and stabilities that conform to industry standard packages. We also offer a unique family of ultra-low-power OCXO designs (150mW) suitable for battery powered applications. With wide temperature ranges, high frequencies, the lowest power and industry leading phase noise and stability, CTS OCXOs offer a performance advantage to our customers.

CTS PRODUCTS

	Model	Features	Frequency (MHz)	Package Size (mm)	Stability
	122	Low Power Low phase noise Ultra stable	8 to 100	20 x 20	±0.2 ppb
	138	Stratum 3E Small size SMD or TH	10 to 26	20 x 13	10 ppb pk-pk
	149	Stratum 3E Miniature size SMD	10 to 50	14.9 x 9.7	10 ppb pk-pk
	197	1 μsec/8 hr holdover Euro-package	10	36 x 27	0.2 ppb pk-pk
	VFOV302	Stratum 2 Low phase noise Euro-package	8 to 100	35 x 27	±0.1 ppb
	VFOV414	150 mW S.S. power Low phase noise Ruggedized (500 g shock) SMD or TH	8 to 300	22 x 15	±5 ppb
	VFOV415	150 mW S.S. power Low phase noise Ruggedized (500 g shock) SMD or TH	8 to 150	16 x 15	±3 ppb
	VFOV514	150 mW S.S. power Low phase noise Ruggedized (500 g shock) SMD or TH	8 to 150	22 x 15	±1 ppb

ENGINEERING CONSULTATION

CTS provides complimentary consultations with one of our specialized design engineers to assist you in designing your embedded technology-based product or system.

Picking the right frequency control component is critical for success. Comparing hundreds of available frequency control components is time consuming. Consult a CTS engineer to save time in evaluating the right component for your project.

Leverage our engineering expertise. We encourage you to tap into our engineers' collective knowledge base to solve your most complex design issues and find the best solution to meet your needs, no matter the application.

With a comprehensive portfolio of frequency control components, our engineers have a vast foundation of solutions to meet your requirements. However, if you need turnkey product development or a custom configuration to fit a specific application, our engineers are available to consult with you on how CTS can fulfill custom modifications to your meet your project specifications.

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ABOUT CTS

CTS (NYSE: CTS) is a leading designer and manufacturer of products that Sense, Connect, and Move. The company manufactures sensors, actuators, and electronic components in North America, Europe, and Asia. CTS provides solutions to OEMs in the aerospace, communications, defense, industrial, information technology, medical, and transportation markets.

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