Causes of Crystal Aging in Oscillators

White Paper

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CAUSES OF CRYSTAL AGING IN OSCILLATORS

More applications and system configurations require timing redundancy and local clocking capabilities as part of standard operation. Network elements are designed to operate in both lock mode (system locked to network reference or GPS) or holdover mode. The local timing device must keep the system running with a specific frequency drift rate. Simultaneously, wireless steered GPS applications like ocean floor seismic nodal, military data links, or battery-operated test gears use local oscillators as a backup mechanism to GPS and noise reduction elements. Quartz-based timing devices are most suitable for "clocking backup" and for their well-known performance attributes such as; high Q, long-term accuracy and stability, along with significant cost benefits. This paper will discuss the critical elements affecting frequency drift of quartz crystals in quartz-based oscillators; aging.

AGING IN QUARTZ OSCILLATORS

The term "aging" is sometimes used interchangeably with the term frequency drift, referring to frequency variations with respect to time in quartz oscillators. However, as defined by the International Radio Consultative Committee (CCIR), aging is "the systematic change in frequency with time due to internal changes in the oscillator". In contrast, drift is defined as "the systematic change in frequency with time of an oscillator". Drift is the sum total of crystal aging and other external and environmental factors. For this discussion, we will focus solely on crystal aging.

Typical Aging Behaviors

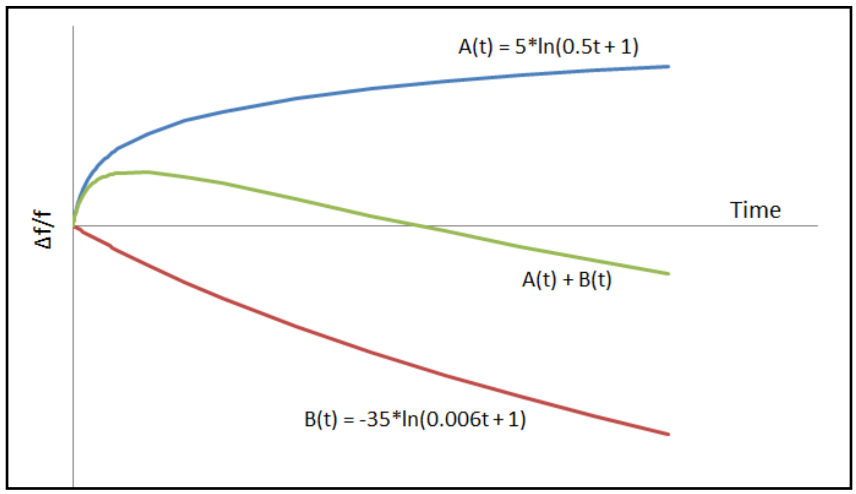

Figure 1. Source: John R. Vig Tutorial, J.Vig@IEEE.org. Approved for Public Release. Distribution unlimited.

Aging is defined as frequency change with time and generally exhibits an exponential positive, decaying frequency drift characteristic. However, the direction of frequency change can be either positive or negative, as illustrated in Figure 1. As shown, several factors may combine in a quartz resonator that defines its aging performance. For instance, a reversal of direction can occur when the quartz resonator is being acted upon by two simultaneous mechanisms of opposing directions with different decay rates.

Two main factors cause crystal aging. The first is mechanical stresses mainly due to changes in stress levels within the resonator's mechanical mounting. The second is molecular contamination, even though precision resonators are processed and sealed in an extremely clean environment under extremely high vacuum conditions. These factors can be grouped into two categories; reversible and non-reversible, including mechanical and thermal stresses, and contamination and molecular migration (mass loading).

REVERSIBLE FACTORS AFFECTING AGING:

- Molecular flow from a higher energy state to one of a lower energy state affecting the mass of the quartz resonator.
- Mechanical stresses across the resonator caused by thermal gradients.

NON-REVERSIBLE FACTORS AFFECTING AGING:

- Relaxation of stresses in the resonator due to manufacturing processes (sawing, lapping, polishing, etc.).
- Relaxation of stresses applied to the resonator by the condensation of the vaporized metal electrode plating.
- Relaxation of stresses placed across the resonator due to the mechanical mount structures.
- Migration of plating into the quartz.

Suppose a resonator is operating at an elevated temperature and left continuously oscillating (as with an Oven Controlled Crystal Oscillator, OCXO). In this scenario, the reversible effects will reach equilibrium, and the non-reversible effects will determine the aging rate. If the oven and oscillator power are interrupted for a period, allowing the resonator to cool down, and then restarted, the resonator will not immediately return to the aging rate and frequency as before the interruption (Figure 2).

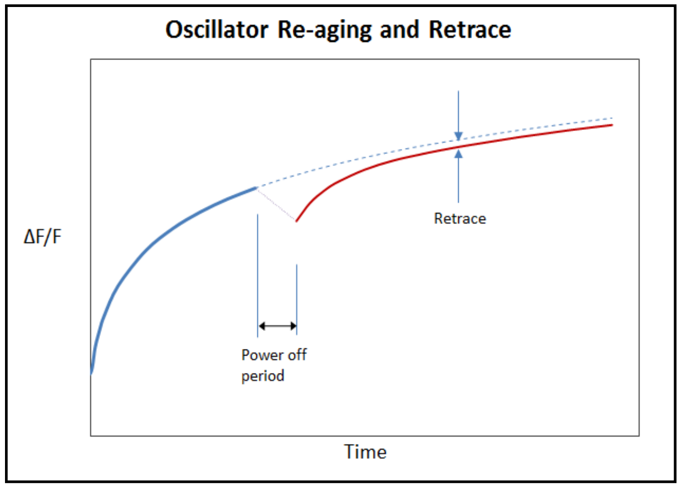

Figure 2. Oscillator re-aging and retrace

THE CAUSES OF THIS DISCONTINUITY ARE PART OF THE REVERSIBLE FACTORS.

- During the off period, the resonator is at a lower energy state than it was while oscillating (in motion). In this lower energy state, the resonator will tend to adsorb gas molecules. The gas molecules will slowly desorb when the oscillator is restarted, and the crystal returns to a high energy state.
- When the resonator is reheated to an elevated temperature, heat is strictly conducted to the crystal plate through the mechanical mounts. As the high vacuum inside the enclosure eliminates convection heating, heating through just the mechanical mounts imparts a thermal gradient (stress) across the resonator.

The thermal shock may affect the non-reversible factors, including induced relaxation of manufacturing and mounting stresses, although these are typically removed by precondition temperature cycling.

The stresses placed within the resonator by rapid thermal change as the oven warms up is a function of the change rate of oven temperature and crystal construction. Therefore, the stresses can remain repeatable in a given design. The adsorption of gases due to non-oscillation is a function of the off time and the level of contaminants available. Therefore, this effect is expected to increase for longer off times and higher contaminant levels.

Asymptotic decaying aging will stop when mass distribution reaches an equilibrium, and stresses stop changing or are completely removed.

Retrace (hysteresis) is a term used to describe how well an oscillator returns to its original frequency accuracy once it has been powered down for a period, then powered back up. The mechanisms that can cause these effects include strain changes in the resonator's mounting structure, changes in the quartz, oscillator circuitry changes, contamination redistribution in the crystal enclosure, and apparent hysteresis or retrace due to thermal gradients[1].

For a quartz oscillator to achieve its ultimate aging rate and frequency accuracy, the ideal application is one in which the device will remain continuously powered. If interruptions in power are unavoidable, the oscillator will not immediately return to its prior rate, due to re-aging and retrace, and will unlikely return to the exact same frequency.

CTS PERFORMS RIGOROUS TESTING.

With CTS' extensive experience designing and manufacturing precision quartz crystals and oscillators, we perform rigorous testing and preconditioning on all our crystals prior to insertion into their final oscillator. The testing CTS performs includes resonator angle measurement and correction, DLD (drive level dependency), temperature test, and fine and gross leak.

CTS preconditioning processes include active burn-in, high-temperature bake, and thermal cycle to reduce stresses before assembly in the oscillator. Additionally, CTS OCXOs are preconditioned with thermal cycle and burn-in/aging in which frequency is continuously monitored and graded to ensure aging compliance.

CTS PROVIDES A VARIETY OF OCXO MODELS

CTS offers several extremely low aging rate oscillators (2.0x10-10/day rate) in multiple package sizes.

Model	Package Size [mm]	Frequency	Stability	Output	Aging	Feature
VFOV200	25x22 SMD	5-250 MHz	±5 ppb -40/+85C	HCMOS/ sinewave	0.2 ppb/day	Low phase noise 3.3V, 5V, or 12V
VFOV302	35x27 TH	8-100 MHz	± 0.1 ppb -20/+60C, ± 0.3 ppb -40/+85C	HCMOS or sinewave	0.2 ppb/day	Low phase noise 5V, or 12V
197	36x27x12.7 TH	10 MHz	±1.0 ppb pk-pk, -40/+85C	Sinewave	0.2 ppb/day	1.5 µsec/8 hour holdover
144/148	15x15 15x25 TH	8- 120 MHz	±5ppb, -30/+70C	HCMOS	0.5 ppb/day	Ultra low power, low G-sens
138	13x20x11 SMD/TH	10- 26 MHz	±10 ppb pk-pk, -40/+85C	HCMOS	1 ppb/day	Stratum 3E
118	25x25 SMD or TH	10- 40 MHz	±6ppb, -40/+85C˚	HCMOS/ Sinewave	1 ppb/day	Stratum 3E
119	22x25x12 SMD	10- 26 MHz	±10 ppb pk-pk, -40/+85C	HCMOS	1 ppb/day	Stratum 3E
149	14x9x7 SMD	10- 50 MHz	±20 ppb, -40/+85C	HCMOS	2 ppb/day	Smallest size

ABOUT CTS

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