Hysteresis Measurements of 20 MHz Third Overtone SC-cut MCXO Resonators

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Abstract

The Microcomputer Compensated Crystal Oscillator (MCXO) utilizes dual c-mode excitation of an SC-cut resonator for self-temperature sensing and compensation. The dual mode operation requires well-behaved fundamental and 3rd overtone c-modes over the operating temperature range (e.g. -55°C to +85°C). The stability of MCXO depends primarily on the frequency vs. temperature hysteresis of the resonator. The hysteresis of the 10 MHz 3rd overtone SC-cut resonator used in the MCXO up to now has been a few parts in 10^8 [2,8]. This resonator is packaged in an HC-40 metal can, which makes the resonator the largest single component in the MCXO. The size of this resonator has limited efforts to reduce the size of the MCXO.

In this paper, results of hysteresis measurements of a 20 MHz 3rd overtone SC-cut resonator packaged in a TO-5 metal can (~13% the volume and ~57% the height of the HC-40 package) is reported. Hysteresis over the -55°C to +85°C temperature range was found to be a few parts in 10^8, comparable to that of the 10MHz 3rd overtone resonator.

Introduction

The microcomputer compensated crystal oscillator (MCXO) is an oscillator capable of providing a 10 to 100-times improvement in overall frequency accuracy when compared to conventional TCXOs. It employs no crystal "pulling." It thus permits the use of a low hysteresis, "stiff," high-stability SC-cut crystal in a non-trimmed oscillator. Resonator self-temperature-sensing, using a dual mode oscillator, virtually eliminates thermometry-related errors. MCXOs can provide a timekeeping accuracy of 100 μs per hour, with an input power of less than 40 milliwatts. Long term accuracy is parts in ~10^8 per year [1-8].

Dual mode operation requires well-behaved fundamental and 3rd overtone c-modes over the operating temperature range (e.g. -55°C to +85°C). The stability of the MCXO depends primarily on the frequency vs. temperature hysteresis of the resonator. The hysteresis of the 10 MHz 3rd overtone resonator used in the MCXO up to now has been a few parts in 10^8 [2,8]. This resonator is packaged in an HC-40 metal can, which makes the resonator the largest single component in the MCXO. The size of this resonator has limited the efforts to reduce the size of the MCXO.

A Small MCXO Resonator

A 20 MHz 3rd overtone SC-cut resonator design has been found which provides well-behaved fundamental mode and 3rd overtone c-mode frequency vs. temperature characteristics over at least a -55°C to +85°C operating temperature range.

The resonator uses a 6.4 mm diameter blank that is plano-convex, with a 9.0 or 9.5 diopter contour. The surfaces were finished with a 1 μm abrasive and they were chemically polished in a 4:1 solution of NH₄F:HF [9]. The electrodes were 3.3 mm diameter, Cr-Au, with tabs along the X-axis. A four-point mount was used, with 76 μm thick × 510 μm wide nickel V-type mounting clips. The bonding agent was a silver-filled polyimide [10]. The package was an HC-35/U (TO-5). The resonators were UV-ozone cleaned [11] and baked at 300°C for 10 hours prior to sealing. The crystals were transferred to a cold-weld sealer and were sealed at ~150°C in a cryopumped vacuum system.
The 20 MHz 3rd overtone resonator is ~13% the volume and ~57% the height of the HC-40 package. The Q values are about ~1.1 million and ~0.7 million for the fundamental and 3rd overtone modes, respectively.

**Hysteresis Measurement**

The stability of the MCXO depends primarily on the frequency vs. temperature hysteresis of the resonator [12,13]. Hysteresis was measured two ways, in a \( \pi \)-network and in a dual-mode oscillator.

Fig. 1 shows a schematic diagram of the \( \pi \)-network based measurement setup. In this setup, it is not possible to simultaneously measure the two modes; thus, the temperature fluctuation induced frequency measurement errors are unavoidable. To reduce these errors, a technique reported previously [2] was applied; i.e., after stabilizing at each target temperature, the fundamental and 3rd overtone modes were sequentially measured several times. Each fundamental mode frequency was matched to the average of the two 3rd overtone frequency measurements that were made immediately before and immediately after the fundamental mode frequency measurements.

Fig. 2 shows a schematic diagram of the dual-mode crystal oscillator (DMXO) measurement setup. The dual modes were measured simultaneously with two frequency counters which used a cesium standard for a time base. The counters were triggered simultaneously to eliminate errors due to temperature fluctuations.

The measurements started at \(-55^\circ\text{C}\) after stabilization for at least 40 minutes at \(-55^\circ\text{C}\). The temperature was increased to \(+85^\circ\text{C}\) and then decreased back to \(-55^\circ\text{C}\) in steps of \(4^\circ\text{C}\). To reduce temperature fluctuations, the resonators and DMXOs were covered with a thermal tent, and the temperature inside the tent was monitored with a platinum resistance thermometer. The duration per step (stabilization, soak and measurement time) varied from 30 to 50 minutes, depending on the temperature.

Fig. 3 shows the typical relationship between the fundamental and 3rd overtone frequency vs. temperature (f vs. T) characteristics [2]. The beat frequency shown in Fig. 4 monotonically decreases with an almost linear coefficient of \(-33.9\ \text{Hz/}^\circ\text{C}\).

The f vs. T data were fit to a polynomial and the residuals between the polynomial and the measured values were used to determine the hysteresis, as is shown in Fig. 5. A single polynomial was not enough to fit the f vs. \(f_0\) with sufficient accuracy [2]; therefore, a five-segment 9th order polynomial was used for the least squares fitting.
Fig. 5 also shows the hysteresis of a good resonator measured with the two methods. The dots are the residual values of the measured points and the solid line connects the average of the points at each value of the beat frequency (i.e. each measurement temperature). Both plots show similar hysteresis of about $1 \times 10^{-8}$.

A histogram of 30 resonators' hysteresis, measured with the π-networks, is shown in Fig. 6. Out of the 30 units tested, 26 units are shown, 4 units were "rejects," off the scale of the graph, and 50% of the resonators show less than $3 \times 10^{-8}$ hysteresis. Therefore, hysteresis that is nearly as good as those typical of 10 MHz 3rd overtone SC-cuts can be achieved.

After the π-network measurements, five good resonators were assembled into prototype DMXOs. The hystereses of these DMXOs were 1.0, 1.1, 1.6, 3.0, and $5.3 \times 10^{-8}$. The same units' hystereses in the π-network were 1.1, 2.1, 2.1, 2.9, and $3.9 \times 10^{-8}$.

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**Fig. 3:** Typical frequency vs. temperature curves of fundamental and 3rd overtone modes of a 20 MHz SC-cut resonator.

**Fig. 4:** Beat frequency vs. temperature of a 20 MHz SC-cut resonator.

**Fig. 5:** Hysteresis of the same resonator by two different measurement techniques; (a) π-network, (b) DMXO.
30 resonators tested
4 beyond this histogram scale
1 resonator = $24 \times 10^{-6}$
1 resonator = $-73 \times 10^{-8}$
2 resonators = $-7 \times 10^{-6}$

Fig. 6: Histogram of hysteresis by $\pi$-network measurement.

Conclusion

A 20 MHz 3rd overtone SC-cut resonator may allow a significant reduction in the size of the MCXO, without a significant degradation in the MCXO's stability. It appears that a $6 \times 10^{-8}$ accuracy MCXO will be possible, allowing $3 \times 10^{-8}$ for $f$ vs. $T$ stability, including hysteresis, and $3 \times 10^{-8}$ for one year of aging plus all other instabilities.

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