STATISTICAL RESULTS FROM HIGH VOLUME PRODUCTION OF ULTRA STABLE PRECISION QUARTZ OSCILLATORS

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Abstract

Statistical results from a sample of greater than 10,000 5MHz 260 Series oscillators, designed and developed as an alternative to Rubidium oscillators by MTI-Milliren Technologies, Inc., confirm successful high volume production of this ultra-stable ovenized crystal oscillator. Results from various performance parameters including thermal stability, aging, phase noise, and short-term stability will be presented.

Introduction

This paper is an adjunct to "A High Precision Quartz Oscillator with Performance Comparable to Rubidium Oscillators in Many Respects" presented at the 1996 IEEE Frequency Control Symposium. Since its introduction, the 260 Series oscillator has matured to where large volume production is commonplace. The oscillators, housed in a 50.8mm x 50.8mm x 30.1mm package, are designed to meet many custom specifications. Since the performance specifications differ for each requirement, the data presented has been normalized, as necessary, to provide a more meaningful insight into the results obtained. The data presented has been accumulated by the manufacturing department and stored in an electronic database.

Test Criteria and Statictical Results

The test criteria in a manufacturing environment is to meet customer's specifications. Once the specification has been achieved, further testing to improve the oscillator's performance is not necessary as this would only add manufacturing cost to the product. This artifact of the production environment is most noticeable in the Thermal Stability and Aging measurement results where a large percentage of the distribution exists at the product specification limit.

To enable precise measurements, a high performance HP Cesium clock is used as the frequency reference for all test systems. To ensure the integrity of data collected in large volume production, substantial design considerations were given in developing the test equipment and measurement methods.

Thermal Stability

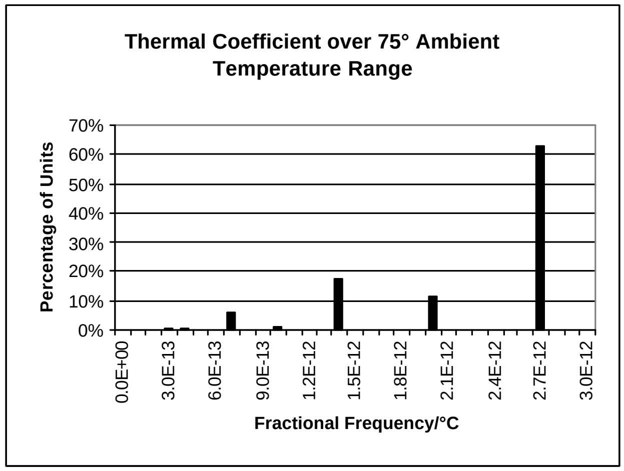

Figure 1

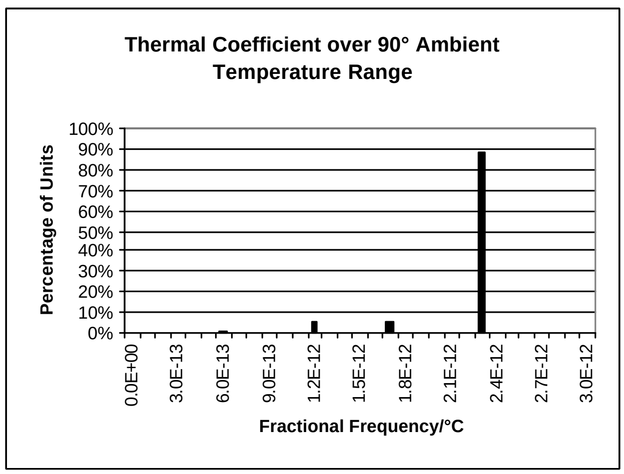

Figure 2

Figures 1 and 2 and 3 show the thermal stability co-efficient for three groups of 260 Series oscillators tested to different specifications. Figure 1 shows the results for a group that was tested to a specification of 2e-10 over an ambient temperature span of 75°C. The mean performance for this group is 2.2e-12/°C. The second group was tested to 2e-10 over a 90°C span with a mean of 2.1e-12/°C and is shown in Figure 2. Group three, shown in Figure 3, comprised of oscillators tested to a specification of 2e-10 over a 100°C ambient temperature span. The mean performance for this group was 1.6e-10.

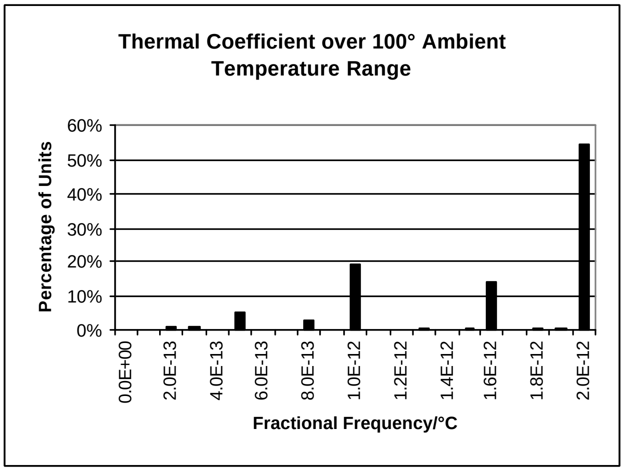

Figure 3

Aging

Aging data is collected approximately every two hours for a minimum of 5 days on all units prior to shipment. The data is curve-fit using a logrithimic type equation to determine the daily aging slope.

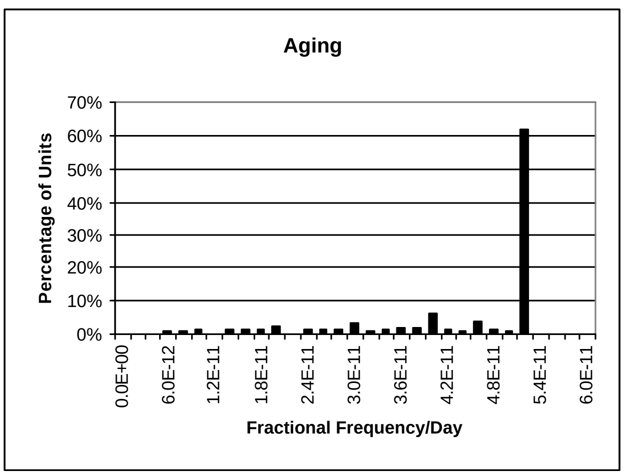

Figure 4

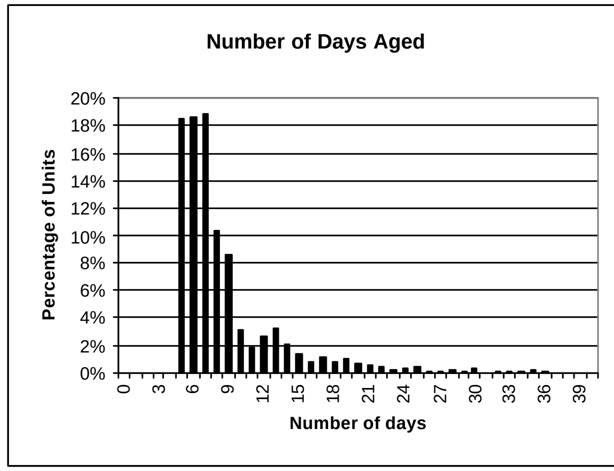

Figure 5

Units are typically shipped as soon as they reach the aging rate specification which, for a majority of the products tested, is 5e-11/day. This is depicted in the aging distribution graph shown in Figure 4. Figure 5 shows the number of days required to achieve the desired specification. However, production overruns may be left on the aging system for extended periods of time.

Output Level and Harmonics

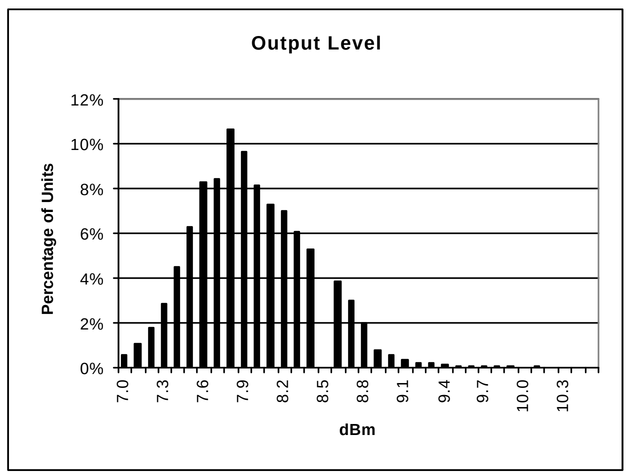

Figure 6

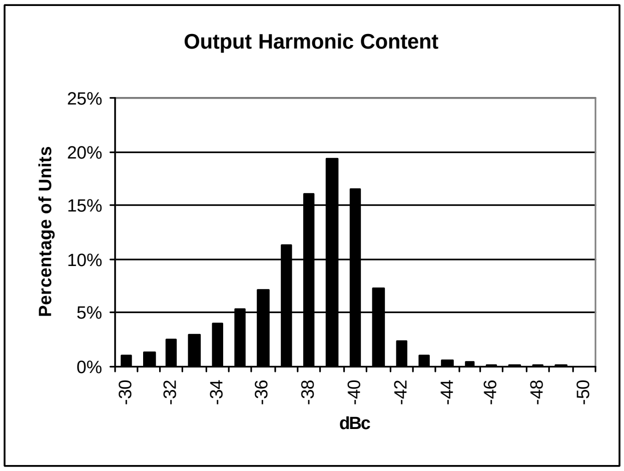

Figure 7

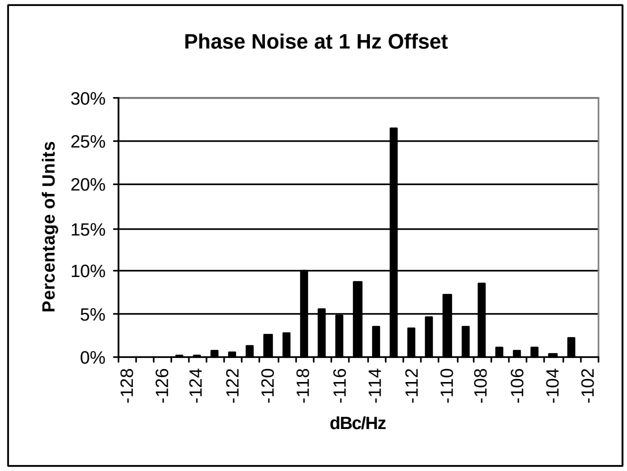

Figure 8

Figures 6 and 7 show the distribution of the output level and harmonic for the 260 Series 5MHz product respectively. All oscillators were designed to meet an output level specification of 9dBm ± 2dB with harmonics of -30dBc maximum. Since this measurement reflects the component parameter distribution in the oscillator circuit and is not a measurement result that is impacted by any adjustments made in the production process, the result for this performance parameter is similar to a bell curve distribution. (The gap in the data shown in Figure 6, and later in Figure 11, is not real. It is an anomaly of the histogram generating routine.)

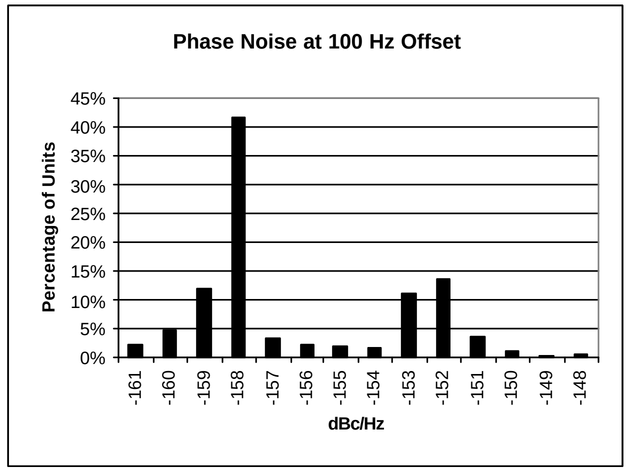

Figure 9

Phase Noise, L(f)

Figures 8, 9, and 10, respectively, show the phase noise performance at 1Hz, 100Hz and 100KHz offsets. The measurements were made using the HP3048 Phase Noise system. The data shown reflects results recorded from the instrument corrected for equal noise sources. The mean performance is -113dBc/Hz at 1Hz offset.

The data in Figure 8 is as much a study of the quartz noise performance as it is of interpretation of test data. The data indicates peaks at -108, -110, -113, -115, and -118dBc/Hz. This is most likely due to the graphical output of the measurement results displayed on a 5dB grid with markers at every 2.5dB increment. The 100KHz offset phase noise measurement made by the HP3048 contains a larger number of data points. Therefore, the data has a greater statistical certainty resulting in a smoother plot which can be more easily interpreted. Additionally, the noise variance in the circuit components which dominates the 100KHz offset performance is much smaller than the quartz crystal noise variance. As a result, the graph shows a smaller variance in the test results recorded and a typical bell curve distribution.

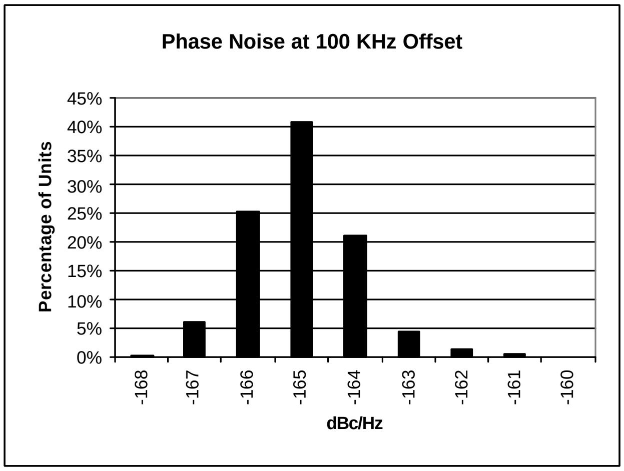

Figure 10

Short Term Stability

The short term stability is derived using the HP3048 system software from the phase noise measurement. The performance distribution is shown in Figure 11. The mean short term stability is 1.1e-12 at 1 second.

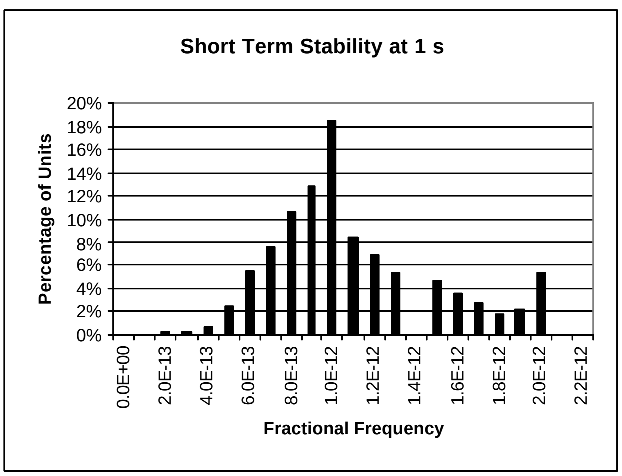

Figure 11

Continuous Power

The continuous power is dependent on both the operating temperature of the oven and the ambient temperature. The continuous power distribution for the 260 Series products is shown in Figure 12. The mean continuous power measured at room temperature is 2.7W. Low power consumption is achieved by circuit design considerations and reduced package size.

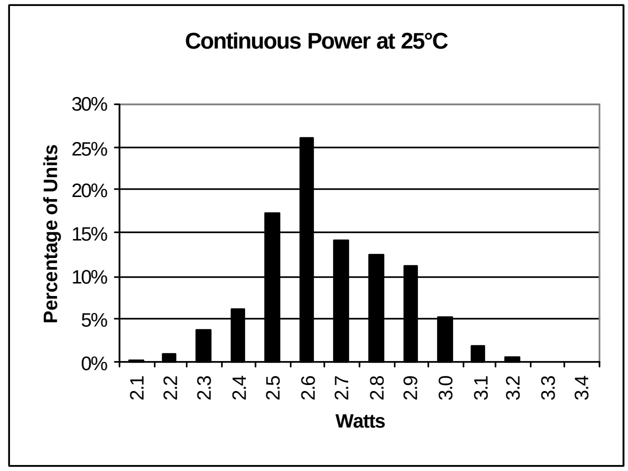

Figure 12

Tuning Coefficient

Figure 13 shows the normalized distribution of the tuning coefficient for the oscillators. The two distributions seen in the graph are primarily due to two different types of tuning networks utilized in the product. The tuning voltage range for all units was 0 to 6V with a negative slope.

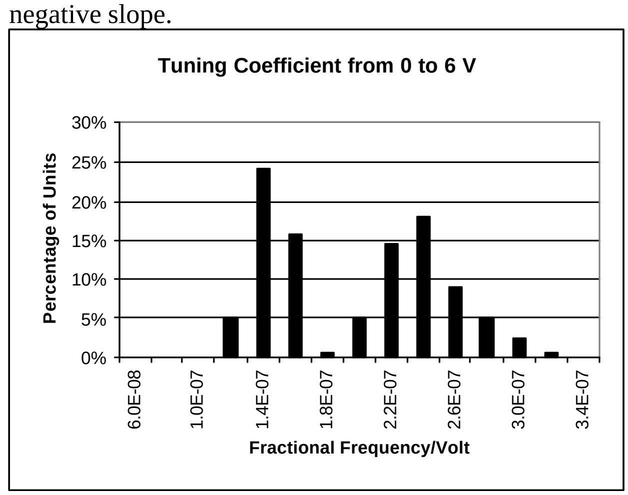

Figure 13

Summary

Table 1 summarizes test data for various the performance parameters measured. The data presented validates the design, manufacturing, and testing methods used, ensuring predictable and repeatable performance in high volume production of the ultra-stable 260 Series quartz crystal oscillator.

Performance Parameter	Units	Sample Size	Min. Value	Max. Value	Mean	Std. Dev.	Avg. Dev. From Mean
Temperature Coeffecient per °C over 75°C Span		7140	1.3E-13	2.7E-12	2.2E-12	6.8E-13	5.9E-13
Temperature Coeffecient per °C over 90°C Span		2732	3.3E-13	2.2E-12	2.1E-12	3.1E-13	1.8E-13
Temperature Coeffecient per °C over 100°C Span		433	1.5E-13	2.0E-12	1.6E-12	5.3E-13	4.7E-13
Aging per Day		10383	5.0E-13	3.9E-10	4.3E-11	1.3E-11	9.8E-12
Number of Days Aged	Days	10383	5	122	10	9	5
Output Level	dBm	10383	7.0	10.3	7.9	0.4	0.3
Harmonics	dBc	10383	-60	-28	-38	3	2
Phase Noise at 1 Hz Offset	dBc/Hz	10387	-128	-98	-113	4	3
Phase Noise at 10 Hz Offset	dBc/Hz	10404	-155	-133	-142	3	2
Phase Noise at 100 Hz Offset	dBc/Hz	10404	-163	-148	-156	3	3
Phase Noise at 1 KHz Offset	dBc/Hz	10403	-166	-153	-162	2	2
Phase Noise at 10 KHz Offset	dBc/Hz	10405	-170	-158	-164	1	1
Phase Noise at 100 KHz Offset	dBc/Hz	10405	-170	-160	-165	1	1
Short Term Stability at 1 s		10405	1.0E-13	3.9E-12	1.1E-12	4.0E-13	3.1E-13
Supply Voltage Sentivity at 12V ±5%		287	1.5E-11	2.5E-10	2.2E-11	1.6E-11	3.6E-12
Warm-up Stability		51	4.2E-11	9.3E-09	1.4E-09	1.7E-09	1.1E-09
Warm-up Time	Minutes	50	6.5	11.0	8.9	0.9	0.6
Warm-up Power	W	10400	10.0	14.4	11.8	0.6	0.5
Continuous Power	W	10400	2.1	3.4	2.7	0.2	0.2
Frequency Offset at 0V Tuning		10013	3.0E-07	1.0E-06	5.6E-07	1.6E-07	1.4E-07
Frequency Offset at 6V Tuning		10013	-1.0E-06	-3.0E-07	-5.6E-07	1.6E-07	1.4E-07
Tuning Coefficient per Volt		10013	1.0E-07	3.3E-07	1.9E-07	5.3E-08	4.8E-08
Reference Voltage	V	10015	5.9	6.4	6.2	0.1	0.1
Tuning Linearity	%	264	3.0	8.0	4.7	1.3	1.1

Table 1

References

[1] M. Vaish, *A High Precision Quartz Oscillator With Performance Comparable To Rubidium Oscillators In Many Respects*, Proceedings of the 1996 IEEE International Frequency Control Symposium, pp. 752-760.