NEL Frequency Controls Inc. Ultra High Frequency Oscillator

NEL Frequency Controls Inc. Ultra High Frequency Oscillator has extended the frequency range of the bulk acoustic wave (BAW) quartz crystal oscillator with its superior frequency tolerance performance into the frequency range traditionally served by the surface acoustic wave (SAW) oscillator with their worse frequency tolerance. NEL uses a patent pending harmonic multiplication method to extend the frequency range, delivering better jitter and phase noise performance (NEL typically obtains -130 dBc/Hz at 10 kHz) than a phase locked loop (PLL) based solution that would also serve this frequency range. This is especially evident in the pass band frequency range of the loop filter of a typical PLL. The uncompensated fixed frequency BAW oscillator (XO) utilizes an overtone of the fundamental frequency to further reduce jitter and phase noise. Thus, the NEL Ultra High Frequency Oscillators (XO, VCXO, and TCXO) have all of the advantages of the traditional BAW crystal oscillator in frequencies up to and even above 1.7 GHz.

NEL Frequency Controls Inc. has been a manufacturer of BAW quartz crystals and oscillators for over 50 years. The AT cut quartz crystal BAW is commonly used at NEL, as well as most of the frequency control industry, for clock oscillators below 300 MHz. NEL has used a patent pending harmonic multiplier method to extend the frequency range using this AT cut BAW resonator design to over 1.7 GHz. The following are some of the advantages that the AT cut BAW has compared to using a SAW based resonator:

- **Low frequency variation with temperature (frequency drift)**. Ideally the AT cut crystal resonator can achieve frequency drift as low as +/-3 ppm 0 to 70 degrees C. (Figure 1) and +/-10 ppm -40 to +85 degrees C.(Figure 2) compared to an ideal SAW crystal resonator having a drift from a centered turnover temperature of -39ppm 0 to 70 degrees C.(Figure 3) and -125 ppm -40 to 85 degrees C. (Figure 4). The AT cut frequency verses temperature curve is a cubic curve having an inflection point very near 25 degrees C. This allows for a nearly symmetrical frequency change plus and minus from room temperature compared to the downward parabolic curve of the SAW resonator.

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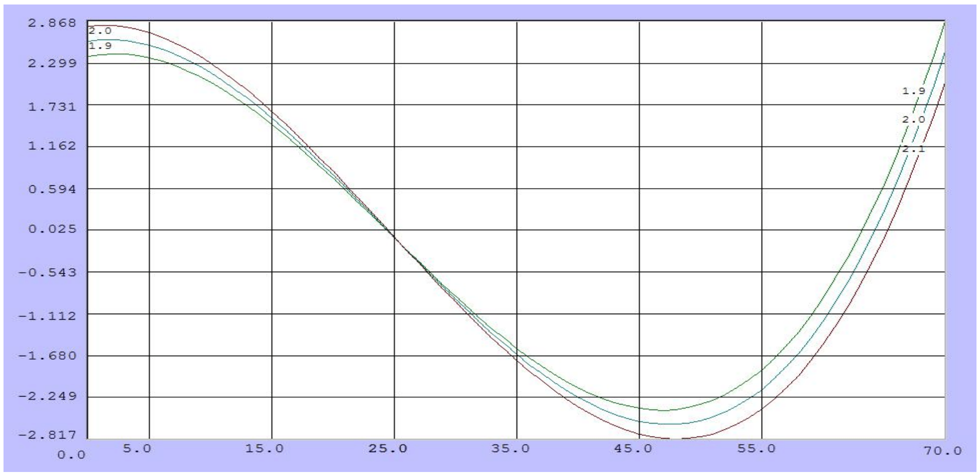

Figure 1 AT cut 0 to 70°C

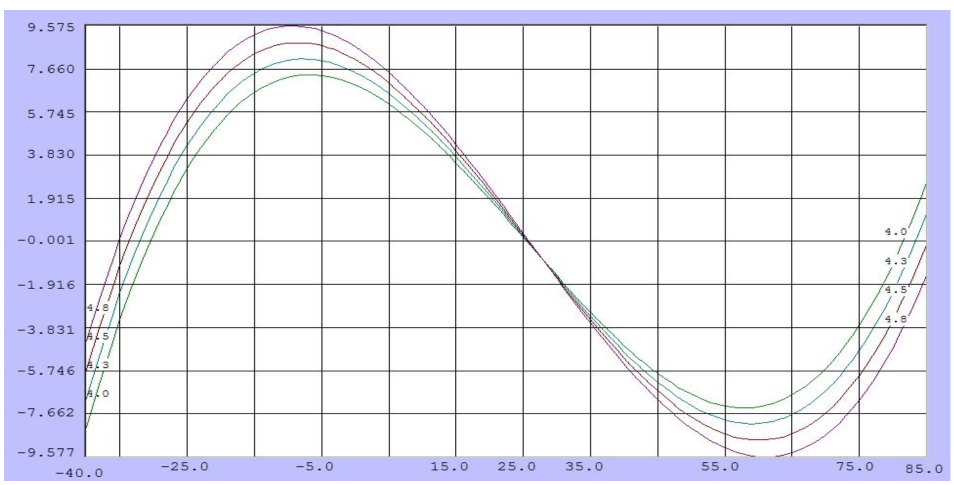

Figure 2 AT cut -40 to 85°C

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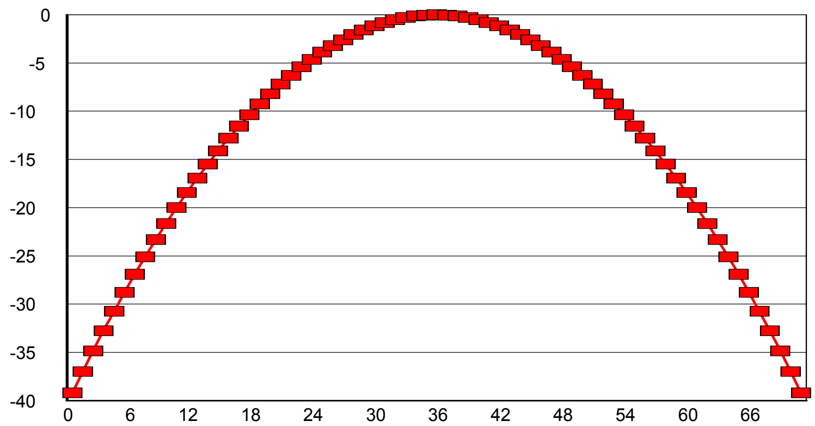

Figure 3 SAW Resonator 0 to 70°C

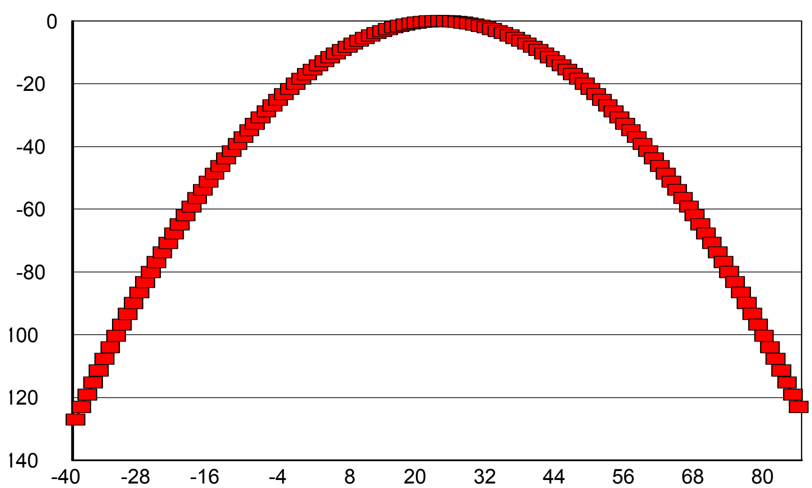

Figure 4 SAW Resonator -40 to 85°C

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- **Tighter initial room temperature frequency tolerance.** AT cut crystals are generally adjusted to frequency in an active circuit prior to sealing. Frequency tolerance of less than +/- 1ppm are obtainable at that time. Frequency tolerances of ±5 ppm are generally available on a production basis as the unit leaves the factory. AT cut crystals are adjusted by either adding material or removing electrode material from the active area of the crystal to adjust the mass loading and thus the frequency of the crystal. The SAW crystal frequency is dependant on the distance between the electrodes making it much more difficult to make final adjustments to the crystal after it has been manufactured. Achieving 5 to 10 ppm at room temperature on a SAW device is less likely on a production basis (typically greater than 20 ppm) than the AT cut crystal. Additional circuitry can be added to either technology to further reduce the tolerance after sealing. This makes the circuit more complicated and additional circuit parameter tradeoffs must be made.

- **Lower Phase Noise and jitter.** Jitter and Phase Noise are affected by a number of variables internal to the oscillator. The bulk of these variables are the same sources as we see causing long term variation in frequency such as capacitance variation with temperature, propagation delay variations with temperature and voltage, frequency changes in the crystal with temperature, etc. The amount of frequency change is dependant on the conditions the unit is subjected to. A comparison of the sensitivity of crystal technologies to these variables can be made by comparing the amount the crystal moves with a given change in the circuit's load capacitance (defined as pullability). Three technologies were selected for this comparison, 1. The traditional bulk crystal operating on the 5th overtone response, 2. The surface acoustic wave (SAW) crystal, and 3. The inverted mesa crystal operating on the fundamental response (inverted mesa is somewhat descriptive of the process of etching away the center of the bulk crystal to get the very high fundamental frequency without losing the strength of the lower frequency bulk crystal). Since the characteristics of each technology changes with frequency, a fixed 310 MHz was selected for comparative purposes. The change in frequency is calculated as follows:

  $\Delta f=(C_1/2)*((C_{L2}-C_{L1})/((C_{L2}+C_0)*(C_{L1}+C_0)$

  Where C_1= Motional Capacitance in pf
  C_0= Shunt Capacitance in pf
  C_{L1}= the higher load capacitance in pf
  C_{L2}= the lower load capacitance in pf
  Δf is unitless and can be converted to ppm by multiplying by 1000000.

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All at 310 MHz

Technology	Shunt Cap. (pf)	Motional Cap. (ff)	Pullability (140pf to 160pf)
5th overtone Bulk Crystal	2.19	0.0876	0.04 ppm
SAW	4.3	2.38	1.01 ppm
Inverted Mesa Bulk Crystal	6.081	28.683	11.82 ppm

From this comparison the 5th overtone bulk crystal would be the stiffest or least likely to move with variation in the circuit, the SAW coming in second and the fundamental inverted mesa being the worst. Thus, assuming the circuit is the same for all three crystal types the jitter would be lower on the 5th overtone crystal compared to the SAW and inverted mesa types.

It is common for higher frequency fixed AT cut crystal oscillators to use the overtone of the crystal to improve jitter, phase noise, ruggedness, and aging characteristics of the oscillator.

- **Typically no tooling cost for custom or uncommon frequencies.** Custom or uncommon frequencies are produced using the same tooling as other frequencies for an AT cut crystal. The quartz thickness and electrode plating are simply adjusted to the proper thickness for the frequency desired. The SAW resonator does require tooling to be done on custom or unique frequencies. SAW tooling is changed when changing frequencies so that the distance between the electrode can be properly adjusted for the given frequency.

Although a PLL design is usually based on a similar AT cut crystal, there are several advantages to the NEL Ultra High Frequency Oscillator solution:

- PLL designs require a higher component count. Generally a low frequency oscillator or crystal, a PLL IC and discrete filter components. This is compared to the single component solution of the NEL Ultra High Frequency Oscillator.
- PLL designs are generally more susceptible to noise injected from outside of the PLL circuit.
- Circuit layout around the loop filter is critical to the phase noise performance of the PLL.
- Phase noise and jitter are normally higher on a PLL design. The phase noise at the frequency range around the band pass of the loop filter is generally higher on the PLL design than on the NEL solution. The phase noise closest to the carrier is generally better on the NEL Ultra High Frequency Oscillator solution since we would use an overtone crystal oscillator design with a higher “Q” than the lower frequency oscillator used in a typical PLL.

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Utilizing the more desirable AT cut crystal oscillator and NEL's patent pending harmonic multiplier we can produce an oscillator with improved frequency stability performance over a SAW based oscillator solution and better jitter/phase noise performance over a PLL based solution.

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