A MINIATURE TCXO FOR GPS/GNSS APPLICATION

Seng-Hsiang KAO [1,*], Ming-Feng TSAO [1], Chien-Wei CHIANG [1], Min-Chiang CHAO [2]

[1]TXC Corporation, Ping Cheng City, Taoyuan County, Taiwan
[2] TXC (Ningbo) Corporation, Ningbo, Zhejiang, China
[*] Corresponding author, E-mail: kennethkao@txc.com.tw

Temperature compensated crystal oscillators (TCXOs) are widely used for mobile communication systems such as personal navigation devices (PNDs) and cell phones. Recently, wearable devices strongly require electronic components inside them to be smaller and thinner. Besides, the close-in phase noise and overall frequency stability also need be considerated for GPS/GNSS application. Therefore, this paper demonstrates the ultra-miniature size TCXO with H-type package to meet such requirements.

Keywords: AT-cut; TCXO; GPS/GNSS; Miniaturization

1. INTRODUCTION

TCXO continues to be used widely in frequency control applications due to its frequency stability and low cost. In this paper, we firstly review the technology trend of TCXO and some requirements of TCXOs used as the primary timing reference for GPS receivers. We then describe the design considerations of the miniature size TCXO of to meet the excellent performance. The unique pattern of package design to achieve the productivity is also presented. Moreover, the appearance and its electrical performance will be insulated in the end.

2. TECHNOLOGY TREND OF TCXO

The conventional analog TCXO employed the resistor thermistor network with several passive components for implementation and it is difficult to downsize since thermistor is not suitable for integrated. In 2001, AKM (Asahi Kasei Microdevices Corporation) presented the fully integrated CMOS analog TCXO IC for cellular phone and other applications. It was designed in a 1.0-um CMOS process with the embedded EEPROM and the temperature stability is better than +/- 2.5 ppm over -30 to 85℃, the chip area is only 2.38 x 1.93 mm^2 [1]. This work starts to drive the crystal oscillator manufacturers to downsize the TCXO module design continually. Today, the TCXO IC chip area can be reduced to less than 1 x 1 mm^2 with the 110 nm CMOS process, a 1.6 x 1.2 mm TCXO module with the temperature stability is better than +/- 0.5 ppm over -30 to 85℃ is very popular. Although the 1.6 x 1.2 mm TCXO is good for most commercial applications, the market is still looking toward even smaller size for wearable devices. We explored the trend of miniaturization of TCXO module for the past 20 years, Table 1 shows the area has be significant reduced from 7.0×5.0mm to 1.2×1.0mm, the miniaturization rate is around 1/30 in view of area due to the advanced TCXO IC design.

Table 1. Relative Area Indictor of TCXO

Year	*Size Name*	*Length*Width (mm)*	*Relative Area Indictor*
1998	7050	7.0*5.0	29.1X
1999	5032	5.0*3.2	13.3X
2002	4025	4.0*2.5	8.3X
2003	3225	3.2*2.5	6.6X
2006	2520	2.5*2.0	4.1X
2008	2016	2.0*1.6	2.6X
2012	1612	1.6*1.2	1.6X
2014	**1210**	**1.2*1.0**	**1X**

In addition, the design and implementation of ultra-miniature size quartz chip is also the big challenge for TCXO module, crystal oscillator manufacturers typically employed the beveled quartz chip to trap the vibration energy in the central area to reduce the effect series resistance (ESR) to meet the capability of negative resistance (-R) offered by TCXO IC. We also plot the miniaturization trend of TCXO in Figure 1. We deduce that miniaturization rate will be decreased slightly in the future due to the design challenge of tiny quartz chip and the process capability of ceramic package.

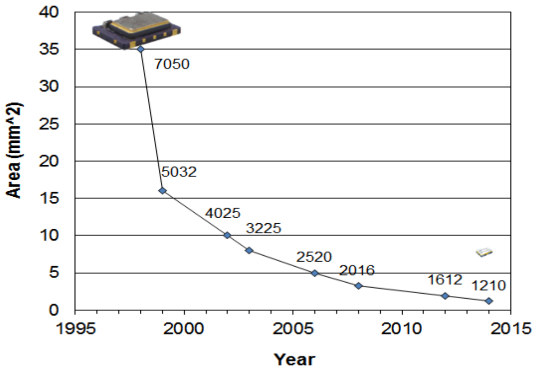

Figure 1. Miniaturization trend of TCXO module

3. TCXO DESIGN CONSIDERATIONS FOR GPS APPLICATION

As recently for 2004, the PLGR (Precision Lightweight GPS Receiver) was the receiver most widely used by the U.S military and it typically cost about US $2,000. For the currently, many mobile devices have the GPS which can acquire satellites levels 100 times than PLGR and just need adds less than US $5 to the cost of mobile devices. The competitive cost make the mobile devices with the built-in GPS functions is rising globally and also driving demand for miniature size TCXOs with high stability performance for accurate positioning.

Figure 2 illustrates the standard GPS receiver architecture [2]. In RF front end, it includes amplifiers, filters, and A-D converters. The antenna received the GPS signal and noise generated by the satellites, then the RF front end transfers the RF signal from RF to IF (Intermediate Frequency) by mixer, filters and A-D converters. The IF is usually in the range of 2-20 MHz based on the receiver design.

In baseband stage, the IF to baseband mixer removes the carrier frequency and keeps the original binary code generated by satellite. The corrector multiplies the noisy signal by a replica of PRN code, the multiplied value are summed by integrator. Therefore, we can find the summed results of all integrations for all possible code dealys and see the characteristic triangular correction peak once the correctors are correctly aligned with incoming signal. The correct frequency of NCO (Numerically Controlled Oscillator) is the key for obtaining the strong correction peak and its performance will be dominated by the local oscillator. In order to keep the sufficient level of correction peak during the weak signal acquisition, the local oscillator (typically is TCXO in consumer GPS) frequency accuracy and stability is one of the most critical factors for excellent GPS/GNSS performance.

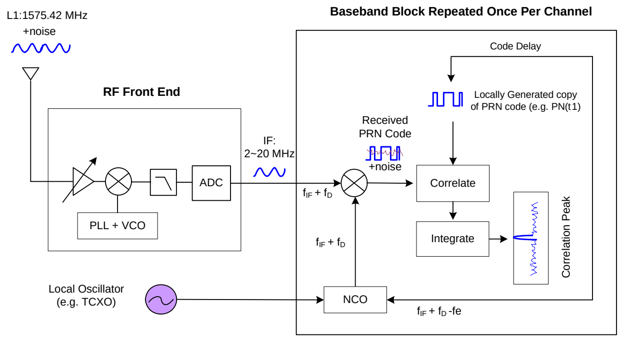

Figure 2. Standard GPS receiver architecture with the RF front end, baseband section and local oscillator

In table 2, there are several performance parameters shall be considered for the TCXO selection. Due to algorithm of search window and requirement of TTFF (Time to First Fix) in GPS receiver, the TCXO needs to have a frequency uncertainty of ±2.0 ppm and ±0.5 ppm over temperature to ensure the GPS signal can be detected. Meanwhile, the time domain clock stability (i.e. drift rate, rAVAR) and phase noise will also affect the ability of a GPS receiver to detect GPS signals. The poor clock stability will result in bad sensitivity and large position errors. Moreover, if the GPS receiver faces the TCXO frequency sudden change significantly, the satellite signal might be missed and the position information will be dropped as well.

Table 2. Critical TCXO Parameters vs. GPS Performance

#	*TCXO Parameter*	*Requirement*	*GPS Impact*
1	Initial Frequency Tolerance	±2 ppm	Time to
2	Frequency vs. Temp	±0.5 ppm	First Fix
	(-30 to 85℃)		
3	Aging	< 1 ppm/yr	
4	Short Term Stability (rAVAR)	< 1 ppb	Weak Signal
5	Frequency Drift Rate	< 5 ppb/s	Acquisition
6	Phase Noise (e.g. 52 MHz)		
	at 10 Hz offset	-74 dBc/Hz	
	at 100 Hz offset	-99 dBc/Hz	
	at 1 kHz offset	-124 dBc/Hz	
	at 10 kHz offset	-134 dBc/Hz	
	at 100 kHz offset	-141 dBc/Hz	
	at 1 MHz offset	-141 dBc/Hz	
7	Frequency Slope vs. Temp	±0.1 ppm/℃	Satellite Signal Missed

A standard block diagram of analog TCXO is shown in Figure 3. Before the calibration process, the VCXO (Voltage Controlled Crystal Oscillator) frequency at 25 ℃ is around +/-15 ppm, with an additional +/-10 ppm (typically) over the operating temperature. After compensation network, the voltage is applied to the varactor in VCXO. The capacitance variation compensates for the crystal's f vs. T characteristic as +/-0.5 ppm (-30~85℃).

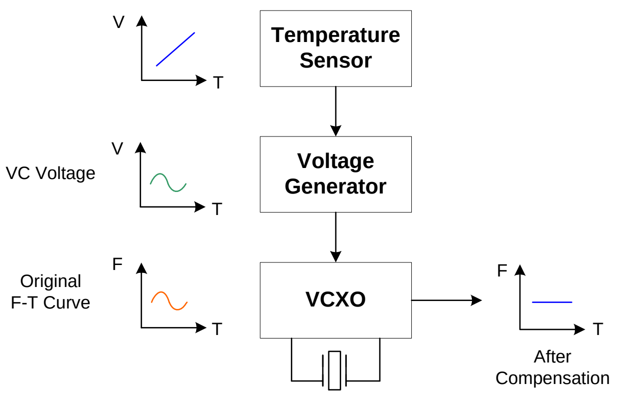

Figure 3. Standard block diagram of analog TCXO

Voltage generator is the key circuit to apply the suitable voltage to VCXO to achieve the excellent performance of frequency stability vs. temperature in TCXO. The basic concept of the desired V-T curve typically can be expressed as the cubic function as in Eq. (1)

$$V(T) = A3(T - T0)^3 + A1(T - T0) + A0 \qquad (1)$$

where *A3* and *A1* are the coefficients in extreme and linear temperature region, *T0* is the reference temperature and *A0* is the DC offset.

After the proper compensation scheme, most suitable coefficient for the *T0* , *A3*, *A1*, and *A0* can be calculated. After writing the corresponding coefficient data to the registers of TCXO IC, the frequency stability can be verified through the temperature sweeping by chamber. The short term stability of TCXO is another key for achieving the excellent GPS performance as mentioned. It is mostly judged by using root Allan variance (rAVAR) [3] for time-domain analysis as in Eq. (2)

$$\sigma(\tau) = \frac{1}{f_0}\sqrt{\frac{1}{2(N-1)}\sum_{i=1}^{N-1}(f_{i+1} - f_i)^2} \qquad (2)$$

where *f0* is the nominal frequency (Hz), *N* is frequency data points, f_i *is i-th* frequency measurement value (Hz), τ is gate time of counter (sec)

The examples to judge the proper/improper root Allan variance are respectively shown in Figure 4 and Figure 5 for design reference.

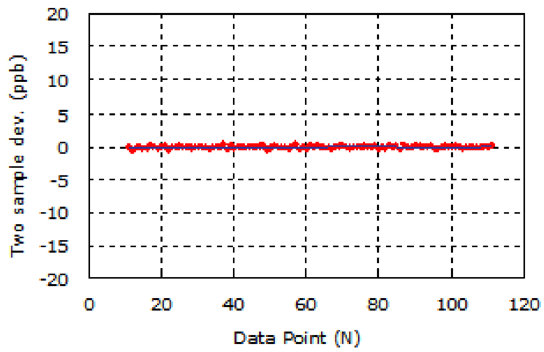

Figure 4. TCXO with proper root Allan variance (rAVAR<1ppb, Tau=1sec)

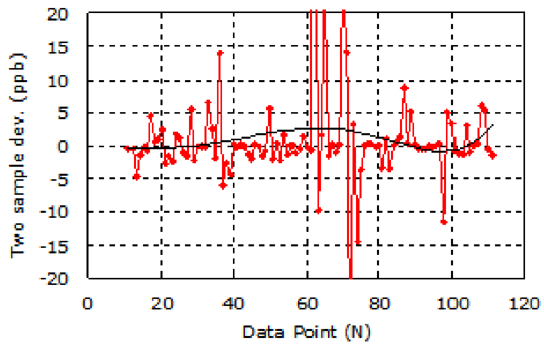

Figure 5. TCXO with improper root Allan variance (rAVAR>5ppb, Tau=1sec)

Figure 6 illustrates the TCXO with H-type package structure. The cross-section of the package is similar to letter H, a hermetic AT-cut quartz resonator is mounted in upper cavity and an IC chip is installed in lower cavity. Unqualified crystal can be inspected and rejected before the flip-chip assembling process.

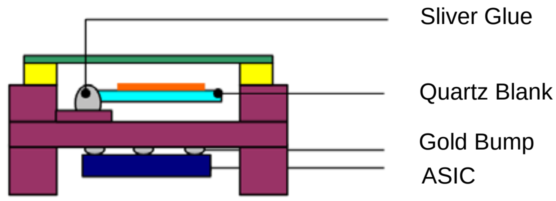

Figure 6. TCXO with H-type package structure

The electrical inspection of crystal during the manufacturing process is also an extremely challenge for such tiny device. In order to maximize the inspection area for crystal, we proposed the unique pattern design (green area) in lower cavity for achieving the productivity in Figure 7.

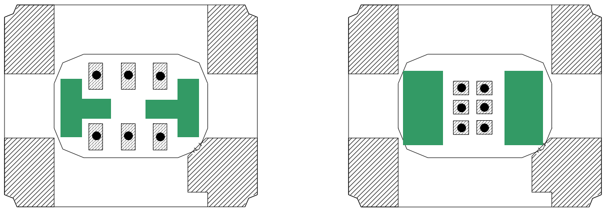

Figure 7. Comparison of the conventional package design (left) and the new design in a 1210 package (right)

4. RESULTS

We completed the 1.2 x 1.0 x 0.5mm TCXO with 52 MHz frequency, supply voltage from 1.68 V to 3.45 V, output is clipped-sinewave with 1.0 Vp-p and 1.7 mA current consumption. Typical close-in phase noise is around -60 dBc/Hz at 1 Hz offset, frequency stability can meet the +/-0.5 ppm over -30 ~ 85℃, rAVAR is less than 0.5 ppb to satisfy the GPS requirements.

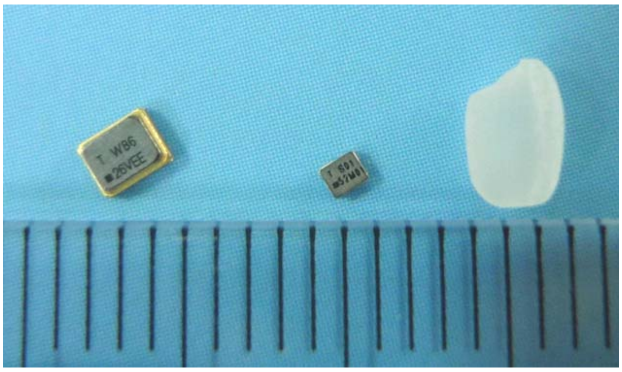

Figure 8. Comparison of the mainstream product in 2520 size (left) and the new product in 1210 size (right)

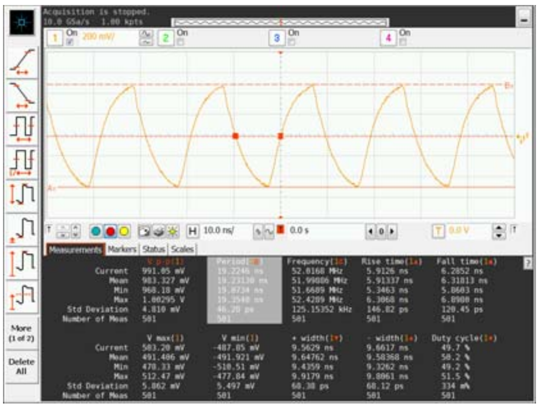

Figure 9. TCXO Clipped-sinewave output with 1.0 Vp-p

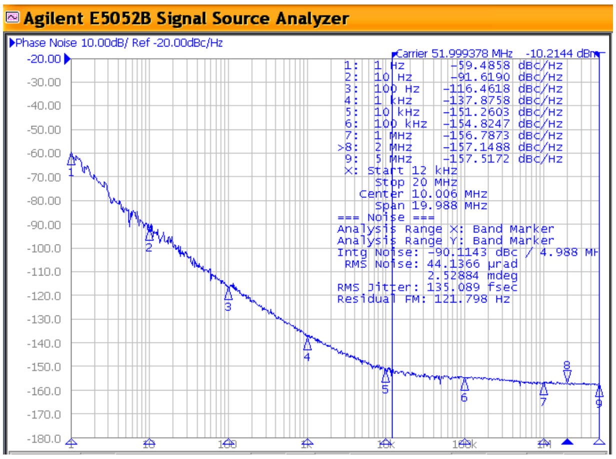

Figure 10. Phase noise measurement of 52 MHz TCXO (1210 size)

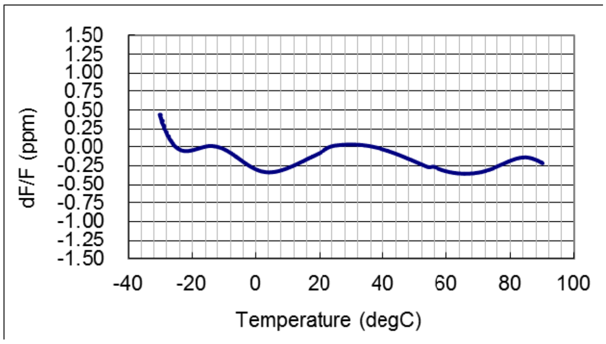

Figure 11. Frequency stability vs. temperature

5. CONCLUSION

In this paper, we demonstrated the first implementation of 1.2 x 1.0 mm TCXO with hermetic AT-cut quartz resonator. The presented measurement data validates the feasibility by using this TCXO to achieve the excellent frequency stability and phase noise for GPS/GNSS receiver applications. The miniature work presents the potential for reducing the footprint design of wearable devices. An optimized solution for improving the current consumption is the next challenge.

REFERENCES

[1] Kenji Nemoto, Ken-ichi Sato. The 2.5 ppm fully integrated CMOS analog TCXO. *IEEE UFFC Symp.*, 2001.

[2] Frank van Diggelen. *A-GPS: Assisted GPS, GNSS, and SBAS,* Artech House Publishers, Massachusetts, 2009.

[3] Agilent Technology. Simplify Frequency Stability Measurement with Built-in Allan Variance Analysis, Application Note 358-12, 1990.