Methods for Achieving High-Frequency Output (Part 2: SAW Oscillators)

SAW Overview and Introduction of Properties

Preface

The previous Technical Notes introduced methods for achieving high-frequency output by combining AT-cut crystal units with a frequency multiplier or PLL circuits. While these methods are capable of utilizing the temperature characteristics of crystal units, these methods do present problems, including the complexity of crystal oscillation circuit design and the difficulty of limiting jitter and phase noise. If we can achieve high-frequency fundamental oscillation using crystal devices, it then becomes possible to limit harmonic components, so we can achieve an output signal with superior jitter and phase noise characteristics. However, the oscillation frequency of AT-cut crystals is determined by the thickness of the crystal chip, thus achieving oscillation at a high frequency requires producing thin crystal chips, to which there are limits due to problems that arise in relation to processing methods and mechanical strength. In these Technical Notes, we examine oscillators that use SAW (Surface Acoustic Wave) resonators, which are capable of solving these problems and achieving direct high-frequency fundamental oscillation.

1. SAW Resonators

Similar to the way waves travel across the surface of a body of water, SAW is a wave propagated by concentrating energy on the surface of an elastic body. The amplitude of the wave decays exponentially in the depth direction. As shown in Figure 1, SAW can be both generated and detected via an IDT (Inter Digital Transducer) mounted on a piezoelectric substrate. The frequency (f) can be derived using the formula, $f = V/\lambda$ where surface wave propagation speed is V and the IDT cycle is λ. The optimal frequency band for SAW devices is approximately 10 MHz to 2 GHz and the upper and lower limits are determined based on the resolution of the thin electrode pattern as well as the characteristics and size of the substrate material. As shown in Figure 2, SAW resonators can be divided into two types: one port resonators and two port resonators. The structure of a one port SAW resonator is comprised of an IDT mounted in the center of the resonator with reflectors positioned on both sides of the IDT. Enclosing the IDT-induced SAW in between dual reflectors provides a resonator that achieves a high Q. Two port SAW resonators are comprised of two IDTs (input/output) mounted in the center with reflectors arranged on both sides. Similar to the one port SAW resonator, the two port SAW resonator employs the same mechanism to achieve a high Q. The two port SAW resonator is a low-loss, extremely narrow band-pass filter capable of easily achieving oscillation by combining the resonator with an amplifier to form a feedback loop. Because of this, the two port SAW resonator is often used similarly to the one port SAW resonator and particularly achieves its true potential at high frequencies. The phase parameters required by the two port SAW resonator will vary depending on the oscillation circuit being used. As such, phase shift error for the resonance frequency must be specified (180º or 0º).

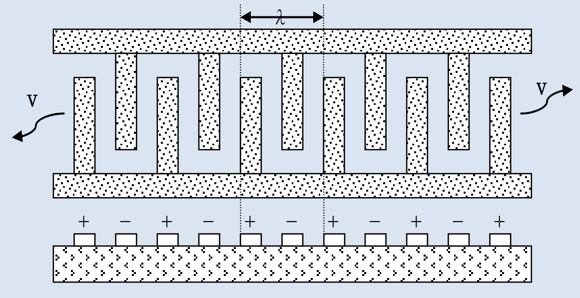

Figure 1: Inter Digital Transducer

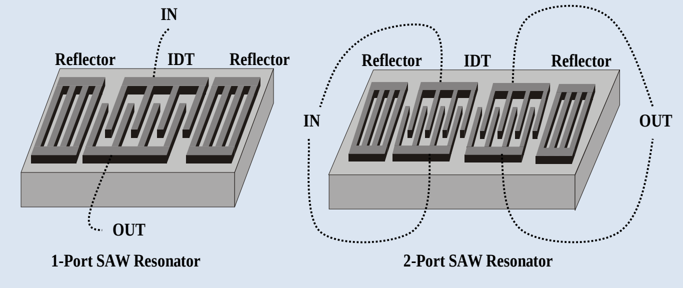

Figure 2: SAW Resonator

2. SAW Resonator characteristics

The SAW resonator vibration mode is based on surface acoustic waves (see Figure 3, right), for which frequency is determined by the width of the IDT formed on the crystal chip and is not dictated by the thickness of the crystal chip. Accordingly, simply changing the IDT pattern enables capability at higher frequency ranges from 10 MHz to several GHz. Comparatively, the vibration of AT crystals is based on thickness-shear mode resonation (see Figure 3, left) where the frequency is determined by crystal thickness. Here, limits to the ability to produce thinner crystal chips mean that the typical compatible frequency range is 10 MHz to 50 MHz for fundamental frequencies and 50 MHz to 150 MHz in 3^{rd} overtone.

Other characteristics of SAW resonators include experiencing lower impact on the main oscillation from vibration (noise) compared to the thickness-shear mode of AT crystals and achieving superior durability against foreign objects that attach to the electrode film due to the protective film formed on the IDT, which is the SAW resonator electrode. These merits provide low jitter when the resonator is mounted to an oscillator and make it possible to eliminate risks such as oscillation stoppage.

Conversely, as shown in Figure 4 (left), compared to AT crystals, which have characteristic for having a cubic curve with an inflection point near room temperature, the temperature characteristics of SAW resonators are fundamentally based on a quadratic curve (Figure 4, dotted line at right). As such, it is generally accepted that it is more beneficial to choose the AT oscillator if you require stable characteristics at a broad range of temperatures.

Epson provides SAW resonator products that utilize proprietary technology to moderately improve the fluctuation range of the quadratic curve compared to typical temperature characteristics (Figure 4, solid line at right) as well as high-precision products capable of achieving stable performance over a wide temperature range (Figure 4, red line at right) similar to the temperature characteristics of AT oscillators.

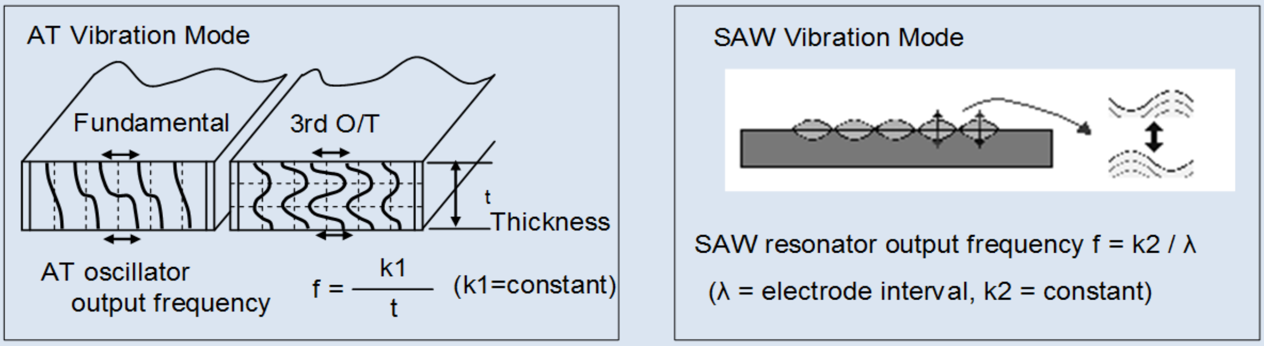

Figure 3: Vibration Modes of AT Crystals and SAW Resonators

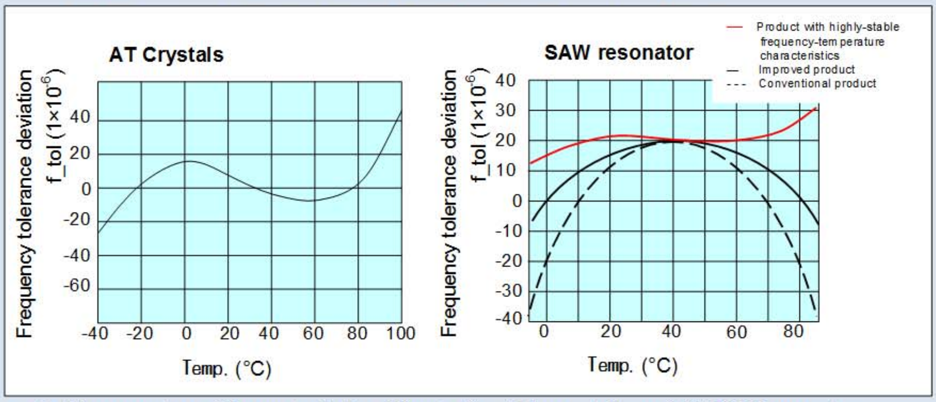

Figure 4: Temperature Characteristics Charts for AT crystals and SAW Resonators

3. Superiority of SAW oscillators [property comparison]

Thus far we have discussed AT oscillators and SAW resonators but a comparison of high-frequency output oscillators (AT+PLL and SAW) used in actual markets found that the points of superiority for SAW oscillators are the phase noise and phase jitter properties they provide as well as their low power consumption. Next, we compare and validate the properties of SAW oscillators against AT+PLL oscillators.

Table 1 Phase jitter and power consumption comparison (3.3V LV-PECL)

Property category (parameter)	Phase jitter (offset frequency: 12kHz~20MHz)	Consumed power (typ.)
SAW oscillator [Epson product] (Product: XG-2102CA)	0.12 ps	45 mA
AT+PLL oscillator [competitor product]	0.27 ps	100 mA

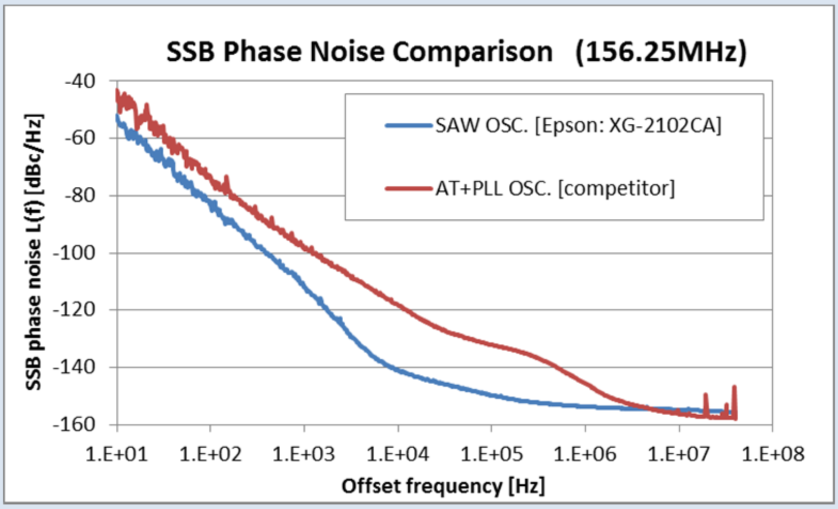

Figure 5 SAW oscillator and AT+PLL oscillator phase noise property comparison

3-1. Phase noise properties and phase jitter

PLL uses a crystal oscillator with a high Q value to rock a voltage-controlled oscillator (VCO) and output a multiplied frequency. As such, phase noise properties are determined by two elements: the crystal oscillation circuit and the VCO. Generally, phase noise properties of the VCO are worse than the crystal oscillator and with PLL the phase noise properties of the VCO will present on the high-pass side, which will cause a section of the phase noise curve to rise. Also, phase noise level on the low-pass side varies with the multiplier, meaning that typically phrase noise properties deteriorate as the multiplier increases.

Products referred to as low-jitter PLL achieve low phase noise by reducing VCO noise and using a low multiplier setting (the AT+PLL oscillator in the above Figure 5 shows the properties for a low-jitter PLL product).

3-2. Power consumption

PLL oscillators comprise a structure based on “oscillation circuit + PLL,” generally meaning that the addition of the PLL circuit requires a greater level of power consumption. Also, as increasing the signal element (amplification) is an effective means of reducing phase noise, these oscillators tend to use more power. Generally speaking, VCOs are designed in the GHz order, which suggest that power consumption is significant.

Conversely, the vibration mode (oscillating source) of SAW oscillators is capable of oscillating at a high fundamental frequency. This allows for a simple circuit structure and makes it possible to constrain power consumption.

As outlined above, SAW oscillators present low phase jitter while also limiting power consumption, making SAW oscillators the optimal electronic component for customers and applications requiring a low bit error rate and low power consumption. Epson offers a wide range of products in our SAW oscillator lineup and will continue to develop products that meet the needs of our customers.