Methods for Achieving High-Frequency Output

Preface

Data transmission speeds and volume continue to increase to support unabated growth in traffic flowing over the Internet backbone largely due to the spread of IoT etc. The need for high-speed communications infrastructure is driving strong demand for high-frequency signal sources that provide stable output signals. Generally speaking, for a MHz range AT-cut crystal unit to oscillate at high frequencies, the thickness of the crystal chip has to be reduced (since the thickness determines the frequency at which an AT-cut crystal unit oscillates) but there are limits in respect to processing methods, mechanical strength, and ease of oscillation. Although it depends on processing accuracy, around 70 MHz is as limitation for the fundamental frequency of AT-cut crystal. For this reason, Epson positioned over around 70 MHz as the high-frequency range. Producing such a stable high-frequency signal is not so simple, but there are four methods (technologies) for achieving high-frequency oscillation. In the first method, an AT-cut crystal unit that produces a relatively manageable oscillation frequency on the order of 20 MHz is combined with a phase-locked loop (PLL) circuit to produce a stable, high-frequency signal. The second method is to use an inverted-mesa type AT-cut crystal unit, wherein only the vibrating portions of the crystal are thinned using photolithography process technology. The third method for producing a high-frequency, stable signal is to use a surface acoustic wave (SAW) resonator, which directly oscillates at a high frequency fundamental. The fourth method is to use a vibration mode (overtone) that vibrates at a high order of the AT-cut crystal unit. This Technical Notes provide a summary explanation of the first method, the method using PLL circuits and the second method is to use an inverted-mesa type AT-cut crystal unit.

1. Overview of PLL circuit and Epson products: Programmable crystal oscillator

(1). PLL circuits

The following is an explanation of PLL circuits, another basic technology for producing stable, high-frequency signals. Semiconductor technology for wireless communications has advanced dramatically with the dissemination of devices that include wireless communications components. Among such technologies, innovation in PLL circuit technology has particularly been astounding.

A PLL circuit generates an output signal that is synchronized with the input reference signal. With the basic structure that comprises of a phase comparator, loop filter, and voltage-controlled oscillator (VCO), a PLL circuit is capable of producing a signal that is accurately synchronized with the input signal.

Unlike frequency multiplier circuits, the source signal is not used for output. PLL circuits use

the VCO to generate a synchronized signal at a frequency that differs from the source signal.

By inserting a frequency demultiplier between the PLL circuit VCO output and the phase comparator input, synchronizing the input signal and divided signal, the VCO output is controlled to a frequency obtained by multiplying the input frequency by the demultiplication ratio. To attain this VCO output to an accuracy equivalent to a crystal oscillator, it is necessary to change the demultiplication ratio while using a crystal oscillator or similar component that can generate stable input signals. This is the principle behind the frequency synthesizer.

Applying this principle, the MHz band output of an AT-cut crystal unit is input to a PLL circuit to create a signal that generates a GHz band carrier wave for use in wireless communications.

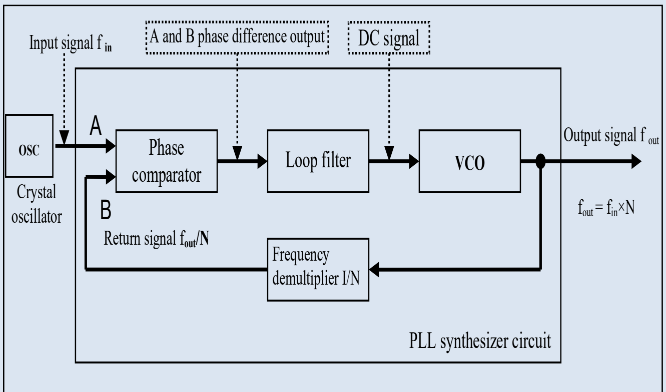


Fig. 1 PLL synthesizer circuit basic structure

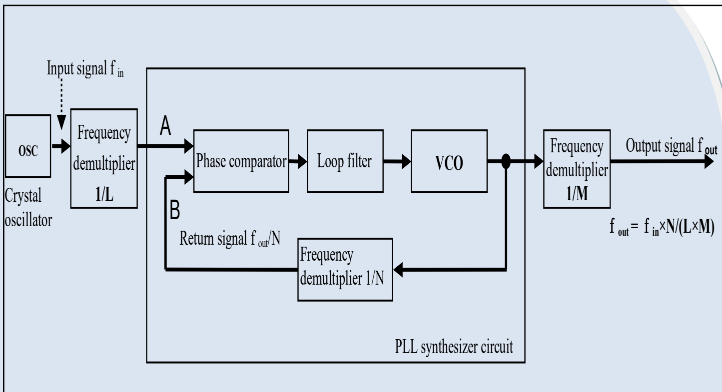


Fig. 2 Example of inserting frequency demultiplier into input

The key to using a PLL circuit to generate a high frequency that is many times greater than the input frequency lies in how the frequency demultiplier is used. The method for achieving nth degree output of the input frequency is the circuit configuration indicated in Figure 1. Also, as shown in Figure 2, inserting a demultiplying circuit before and after the PLL circuit I/O allows for precise adjustments to the output frequency.

A typical means for increasing frequency setting resolution in a PLL circuit involves introducing a frequency demultiplier directly after the crystal oscillation source. However, using a higher divided frequency to increase frequency setting resolution causes a lower phase comparison frequency, which results in a decline in PLL responsiveness and loop gain. These in turn negatively impact on output waveform jitter and phase noise characteristics. A method for resolving this problem is to use a fractional PLL, for example.

(2). Characteristics of Integer PLL and Fractional PLL

PLL circuits are largely divided into two types: integer and fractional. Both types use an oscillating source to output a high-frequency signal. Below is an explanation of major characteristics.
As the name suggests, an integer PLL is capable of creating output frequencies that are integral multiples of the input frequency. For example, if you want to output a 100MHz signal from a 1MHz source, the demultiplier counter setting is 100.

Conversely, a fractional PLL is capable of creating output frequencies that are fractional multiples of the input frequency. The benefit of this circuit is that it allows you to select any frequency (enables you to obtain precise frequency setting resolution).

A fractional PLL allows for precise frequency resolution setting, the initial frequency deviation can precisely be controlled with these properties.

However, the downside is that the circuit design is complicated and the size of an IC becomes larger when compared to integer PLLs, meaning that a particular spurious tends to occur. However, with recent technological advancements, efforts are progressing to reduce the occurrence of spurious which thus far has been a weakness of using fractional PLLs.

(3). Epson product lineup and product features

Above, we examined methods for employing PLL circuits as a way to achieve high-frequency output. The greatest characteristic of these methods is the ability to create a desired frequency at will. In other words, these methods provide necessary frequencies, including high frequencies, when you need them.

Epson's SG-8018, SG-8101 series, which utilizes the fractional PLL circuit technology introduced above, offers a diverse product lineup featuring various sizes (Table 1). We also offer a ROM writer (SG-Writer II) as a programming tool that allows customers to write frequency commands to the SG-8000 series

The SG-8018, SG-8101 series uses an AT-cut crystal unit. The cubic curve temperature properties of the AT-cut crystal unit, which maintains given temperature stability, enables us to offer products with smooth frequency characteristics without frequency jumps.
(Oscillators with first-order linearity of significant temperature properties such as Si-MEMS oscillators require circuit compensations to maintain stability at a given temperature and can result in an occurrence of frequency jumps.)
Furthermore, despite using a PLL circuit, the SG-820x series has jitter characteristics similar to general SPXOs (approximately 1/25 that of the SG-8101) and can operate up to +125 °C.
For details, please see the technical note : Low jitter technology for programmable oscillator
We look forward to helping our customers experience the highly accurate characteristics of these crystal units combined with the convenience of discretionary frequency settings achieved through the PLL circuit technology.

Table 1: Recommended Programmable crystal oscillator product lineup

Model name	Size [mm]	Output	Supply voltage [V]	Output frequency range [MHz]	Frequency tolerance/ Operating temperature [x10^-6 / °C to °C]
SG-8018CA SG-8018CB SG-8018CE SG-8018CG	CA :7.0 x 5.0 x 1.3 CB :5.0 x 3.2 x 1.1 CE :3.2 x 2.5 x 1.05 CG :2.5 x 2.0 x 0.7	CMOS	1.8 2.5 3.3	0.67 to 170	±50 / -40 to +105
SG-8101CA SG-8101CB SG-8101CE SG-8101CG	CA :7.0 x 5.0 x 1.3 CB :5.0 x 3.2 x 1.1 CE :3.2 x 2.5 x 1.05 CG :2.5 x 2.0 x 0.7	CMOS	1.8 2.5 3.3	0.67 to 170	±15 / -40 to +85 ±20 / -40 to +105 ±50 / -40 to +105
SG-8101CGA (AEC-Q100)	2.5 x 2.0 x 0.7	CMOS	1.8 2.5 3.3	0.67 to 170	±15 / -40 to +85 ±20 / -40 to +105 ±50 / -40 to +125 ±100 / -40 to +125
SG-8200CG SG-8200CJ	2.5 x 2.0 x 0.74 2.0 x 1.6 x 0.6	CMOS	1.8 2.5 3.3	1.2 to 170	±50 / -40 to +125
SG-8200CG SG-8200CJ	2.5 x 2.0 x 0.74 2.0 x 1.6 x 0.6	CMOS	1.8 2.5 3.3	1.2 to 170	±15 / -40 to +105 ±25 / -40 to +125
SG-8201CJA (AEC-Q100)	2.0 x 1.6 x 0.6	CMOS	1.8 2.5 3.3	1.2 to 170	±15 / -40 to +105 ±25 / -40 to +125 ±50 / -40 to +125

2.Overview of Inverted-Mesa AT cut Crystal Units: HFF Crystal Units and Their Characteristics

(1). Inverted-mesa AT-cut crystal Units: HFF(High Frequency Fundamental) Crystal Units

A mesa is a land formation that has steep walls and a flat top. Semiconductor products such as transistors that have been processed such that they have a trapezoidal shape when viewed in cross-section are generally called "mesa structures." An inverted-mesa AT-cut crystal: HFF Crystal Units (hereinafter referred to as “HFF Crystal Units”) is, likewise, a crystal in which the oscillating portion of the plate is thinned by creating a trapezoidal hollow (Fig. 1).

The thinner the crystal chip, the higher the frequency. However, a fundamental frequency of about 70 MHz is generally considered to be the highest frequency obtainable in a stable mass-production process using mechanical grinding (at a chip thickness of about 24 microns). To get a higher frequency than that with an AT-cut crystal, a higher-order vibration mode (usually the third overtone) has ordinarily to be used (to obtain a frequency of from 50 MHz to 150 MHz).

However, a complex circuit is required to control the third overtone or other vibration mode in order to obtain a high frequency. Epson, however, obtains high-frequency vibration in the fundamental mode by using a photolithographic process to reduce the thickness of the oscillating portion of the chip only to a few microns while leaving the surrounding are thicker to preserve mechanical strength.

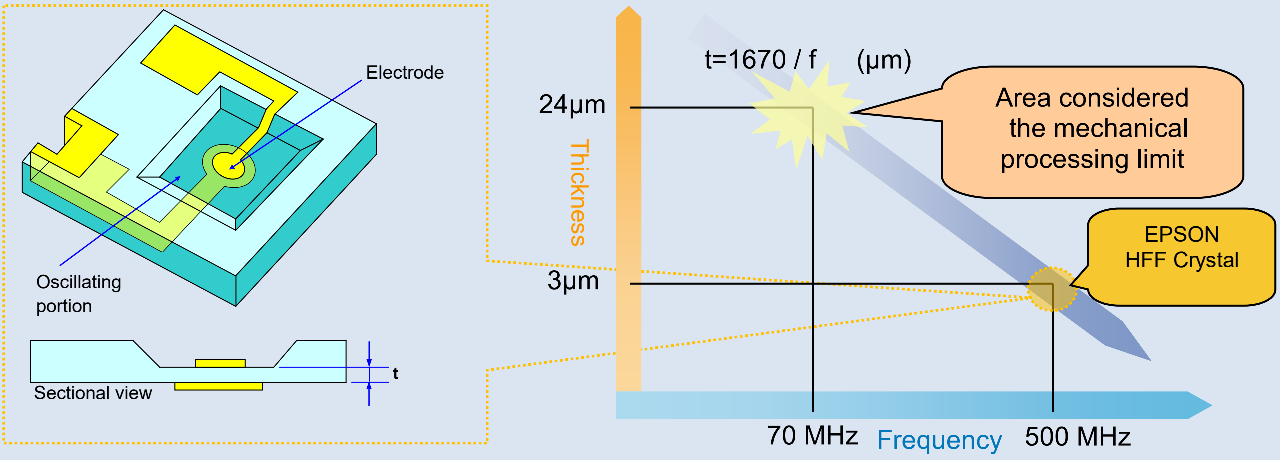


Figure 1. Correlation between HFF Crystal structure, crystal plate thickness, and frequency

(2). Photolithography

Epson can provide small, high-performance crystal devices by performing precise micro-processing on crystal materials using photolithography.
Photolithography is used for several kinds of crystal units besides HFF crystal units. For example, it is used to microfabricate grooved structures on tuning-fork crystal units. It is also used to fabricate AT-cut crystal units that have a mesa structure. Below, I use the fabrication of an AT-cut crystal unit with a mesa structure as an example to explain photolithographic processing technology.

Ideally, crystals that exhibit thickness shear vibration such as AT-cut crystals should oscillate only in the center of the chip; the surrounding areas should not oscillate. This effect can be obtained for some MHz AT-cut crystal units, and especially those that oscillate at low frequency, by beveling the edges of the crystal chip so that the edges and center are different thicknesses.

Figure 2 schematically summarizes conventional mechanical processing and photolithographic processing. In the mechanical process crystal chips are processed by their own weight, so as the crystal chips become smaller, processing becomes more difficult and variation increases, affecting characteristics. In contrast, photolithographic processing enables chips of uniform size and shape, regardless of chip size. Variation can be minimized even for extremely small chips and, moreover, excellent temperature characteristics can be obtained (Figure 3).

Photolithography can likewise be used to create an inverted-mesa structure as shown in Figure 1. This structure enables high-frequency oscillation in the fundamental mode while preserving the chip's mechanical strength, yielding products that have stable performance.

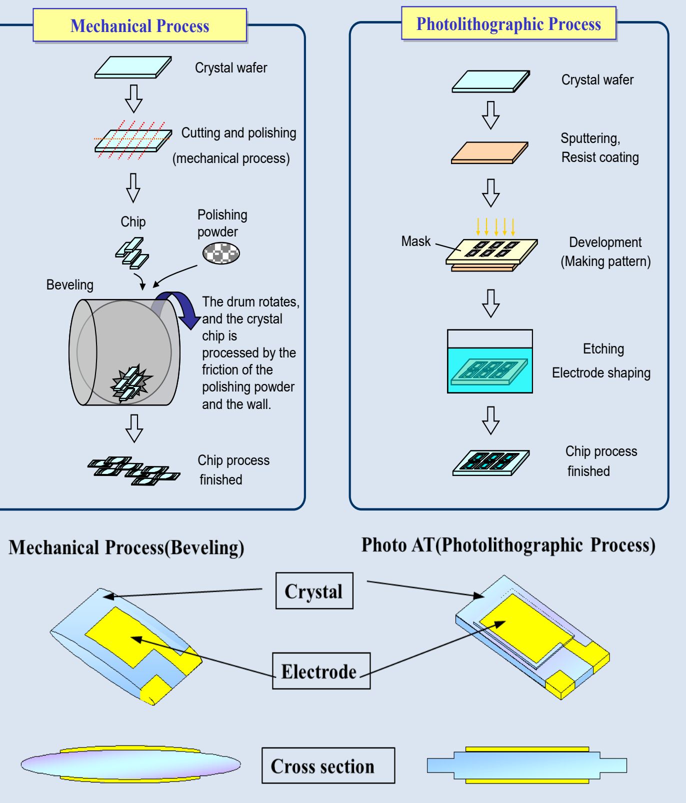
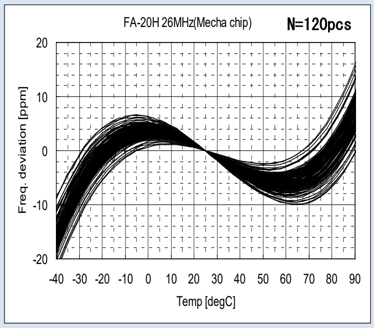
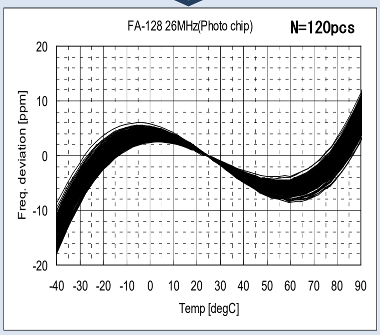


Figure 2. Comparison of crystal chip processing technologies



Temperature characteristics of 2520 size mechanically processed chip



Temperature characteristics of 2016 size chip processed by photolithography

Figure 3. Comparison of temperature characteristic variation

(3). Products and characteristics of products that use HFF Crystal Units

Tables 2 and 3 show Epson products that use HFF Crystal Units that oscillate at a high-frequency fundamental. Table 2 shows the recommended product lineup of XO (Crystal Oscillator), and Table 3 shows the recommended product lineup of VCXO (Voltage Controlled Crystal Oscillator).

A VCXO is a crystal product whose frequency can be controlled via an externally applied voltage. VCXOs are used primarily in cellular base stations and in optical transmission systems. Higher data transmission speeds and higher capacities have increased the need for higher frequencies and more stable signal sources. For this reason, good temperature characteristics and excellent noise characteristics, such as that provided by high-frequency AT-cut crystals, are needed.

Table 2: Recommended product lineup of XO

Model name	Size [mm]	Output	Output frequency range [MHz]	Supply voltage [V] Typ.	Frequency tolerance/ Operating temperature [x10^-6 / °C to °C]
SG2016EHN	2.0 x 1.6 x 0.63	LV-PECL	25 to 500	2.5 3.3	+/- 20 / -40 to +85 +/- 20 / -40 to +105
SG2016VHN	2.0 x 1.6 x 0.63	LVDS	25 to 500	1.8 2.5 3.3	+/- 20 / -40 to +85 +/- 20 / -40 to +105
SG2016HHN	2.0 x 1.6 x 0.63	HCSL	25 to 500	2.5 3.3	+/- 20 / -40 to +85 +/- 20 / -40 to +105
SG2016EGN	2.0 x 1.6 x 0.63	LV-PECL	25 to 500	2.5 3.3	+/-25 / -40 to +85 +/-50 / -40 to +85 +/-25 / -40 to +105 +/-50 / -40 to +105
SG2016VGN	2.0 x 1.6 x 0.63	LVDS	25 to 500	1.8 2.5 3.3	+/-25 / -40 to +85 +/-50 / -40 to +85 +/-25 / -40 to +105 +/-50 / -40 to +105
SG2016HGN	2.0 x 1.6 x 0.63	HCSL	25 to 500	2.5 3.3	+/-25 / -40 to +85 +/-50 / -40 to +85 +/-25 / -40 to +105 +/-50 / -40 to +105
SG2520EHN	2.5 x 2.0 x 0.74	LV-PECL	25 to 500	2.5 3.3	+/- 20 / -40 to +85 +/- 20 / -40 to +105
SG2520VHN	2.5 x 2.0 x 0.74	LVDS	25 to 500	1.8 2.5 3.3	+/- 20 / -40 to +85 +/- 20 / -40 to +105
SG2520HHN	2.5 x 2.0 x 0.74	HCSL	25 to 500	2.5 3.3	+/- 20 / -40 to +85 +/- 20 / -40 to +105
SG2520EGN	2.5 x 2.0 x 0.74	LV-PECL	25 to 500	2.5 3.3	+/-25 / -40 to +85 +/-50 / -40 to +85 +/-25 / -40 to +105 +/-50 / -40 to +105
SG2520VGN	2.5 x 2.0 x 0.74	LVDS	25 to 500	1.8 2.5 3.3	+/-25 / -40 to +85 +/-50 / -40 to +85 +/-25 / -40 to +105 +/-50 / -40 to +105
SG2520HGN	2.5 x 2.0 x 0.74	HCSL	25 to 500	2.5 3.3	+/-25 / -40 to +85 +/-50 / -40 to +85 +/-25 / -40 to +105 +/-50 / -40 to +105

Table 3: Recommended product lineup of VCXO

Supply voltage:3.3 V Typ. Control voltage : 1.65±1.65 V

Model name	Size [mm]	Output	Output frequency range [MHz]	Frequency tolerance /Operating temperature [x10^-6 / ℃ to ℃]	Absolute pull range [x10^-6] Min.
VG3225EFN	3.2 x 2.5 x 1.05	LV-PECL	25 to 500	+/-50 / -40 to 85 +/-50 / -40 to 105	+/- 50 : 25 to 42.5 MHz , 50 to 85 MHz , 100 to 170 MHz +/- 20, +/- 10 : 25 MHz to 250 MHz +/- 10 : 250 MHz to 500 MHz (+85 ℃ Max.)
VG5032EFN	5.0 x 3.2 x 1.3	LV-PECL	25 to 250	+/-50 / -40 to 85 +/-50 / -40 to 105	+/- 50 : 25 to 42.5 MHz , 50 to 85 MHz , 100 to 170 MHz +/- 20, +/- 10 : 25 MHz to 250 MHz
VG7050EFN	7.0 x 5.0 x 1.5	LV-PECL	25 to 250	+/-50 / -40 to 85 +/-50 / -40 to 105	+/- 50 : 25 to 42.5 MHz , 50 to 85 MHz , 100 to 170 MHz +/- 20, +/- 10 : 25 MHz to 250 MHz
VG3225VFN	3.2 x 2.5 x 1.05	LVDS	25 to 500	+/-50 / -40 to 85 +/-50 / -40 to 105	+/- 50 : 25 to 42.5 MHz , 50 to 85 MHz , 100 to 170 MHz +/- 20, +/- 10 : 25 MHz to 250 MHz +/- 10 : 250 MHz to 500 MHz (+85 ℃ Max.)
VG5032VFN	5.0 x 3.2 x 1.3	LVDS	25 to 250	+/-50 / -40 to 85 +/-50 / -40 to 105	+/- 50 : 25 to 42.5 MHz , 50 to 85 MHz , 100 to 170 MHz +/- 20, +/- 10 : 25 MHz to 250 MHz
VG7050VFN	7.0 x 5.0 x 1.5	LVDS	25 to 250	+/-50 / -40 to 85 +/-50 / -40 to 105	+/- 50 : 25 to 42.5 MHz , 50 to 85 MHz , 100 to 170 MHz +/- 20, +/- 10 : 25 MHz to 250 MHz

3. Conclusion

High-frequency signal sources are essential for today's communications equipment and network devices, but there are wide selections of electronic components that produce high-frequency output in order to fulfill a customer's application or desired specifications.

In this article, the following methods discussed how electronic components can provide high-frequency output: (1) convenient programmable oscillators that can be programmed to output a desired frequency; (2) AT-cut oscillators with good temperature characteristics that vibrate directly on the fundamental mode. Every product has a different set of characteristics, but all products are the same in that they take advantage of the stability and accuracy of quartz crystal. Epson offers a wide selection of crystal products that can satisfy almost any application needs. The goal of this technical notes is to adequately explain the high stability of quartz crystal components and hopefully will be of use when one is trying to choose the best electronic component for one’s application.