

# Method for Achieving High-Frequency Output (Part 3: Inverted-Mesa AT Crystal Unit)

## Overview of Inverted-Mesa AT Crystal Units and Their Characteristics

### Preface

Previous articles explained how frequency-multiplier circuits, PLL circuits, and surface acoustic wave (SAW) resonators are used to obtain high-frequency output. Each of these methods produces high frequencies that are stable, but they each have their own advantages and drawbacks. For example, while PLL circuits offer flexibility, they complicate oscillation circuit design and adversely affect phase-noise characteristics. Meanwhile, SAW resonators have the advantage of simple circuit design and good phase-noise characteristics, but their output frequencies fluctuate significantly as temperatures change.

Generally speaking, AT-cut crystals are used more often by crystal manufacturers than the foregoing options. The reasons are that (a) they have an inflection point near room temperature and are frequency-stable over a wide temperature range; (b) they cover a broad range of high frequencies; (c) they can be made smaller than other crystal products because output frequencies are not dependent on the vertical and horizontal dimensions of the crystal chip (also known as a "blank") but can be controlled exclusively by chip thickness; (d) crystal chip fabrication is easy because the cut can be obtained simply by rotating from the Z axis. It would be great if AT-cut crystals could directly oscillate at high frequency, but obtaining high frequencies requires making the crystal chips thinner. Moreover, there is a limit to how high of a fundamental frequency you can obtain because of problems in processing and because of the mechanical weakness of thin crystals.

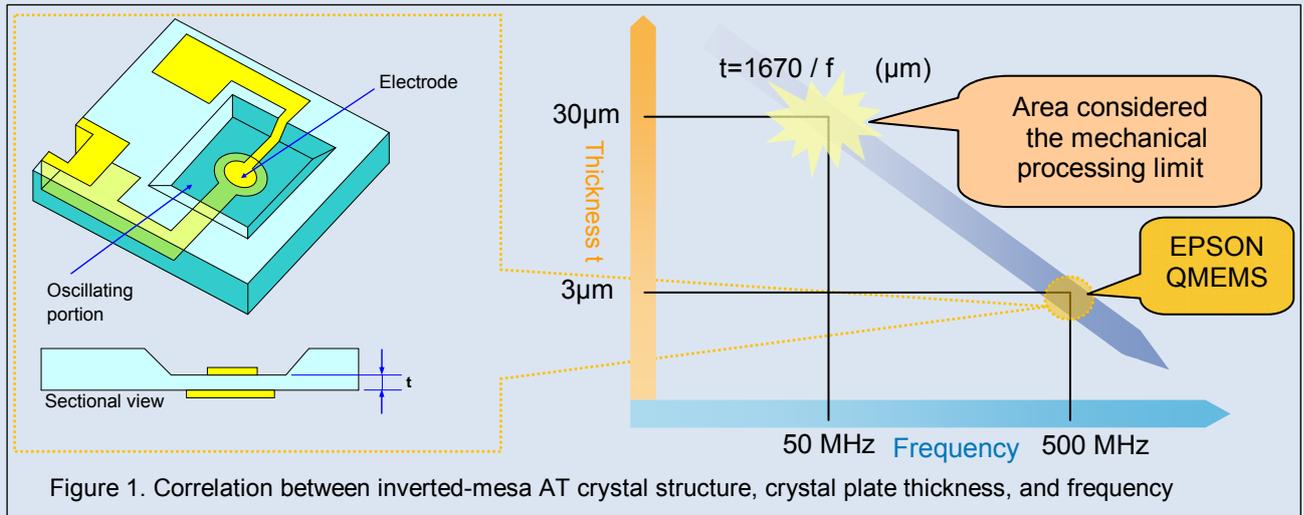
This technical note describes a method for obtaining stable, high-frequency reference signals from AT-cut crystals that have an inverted-mesa design, wherein only the oscillating part of the crystal is thinned using Epson's QMEMS technology.

### 1. Inverted-mesa AT crystals

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 crystal 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 50 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 30 microns). To get a higher frequency than that with an AT 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 QMEMS photolithographic process to reduce the thickness of the oscillating portion of the chip only to a few microns while leaving the surrounding area thicker to preserve mechanical strength.



## 2. QMEMS technology

“QMEMS” is a combination of “Quartz,” a crystalline material with excellent characteristics, including high frequency stability and high precision, and “MEMS” (micro electro mechanical system). QMEMS devices, produced via a microfabrication process on a quartz material instead of on a semiconductor material like MEMS, offer high performance in a compact package. QMEMS technology is used for several kinds of crystal units besides inverted-mesa AT crystal units. For example, it is used to microfabricate grooved structures on tuning-fork crystal units. It is also used to fabricate AT crystal units that have a mesa structure. Below, I use the fabrication of an AT crystal unit with a mesa structure as an example to explain QMEMS processing technology.

Ideally, crystals that exhibit thickness shear vibration such as AT 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 QMEMS 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, QMEMS 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).

QMEMS technology 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.

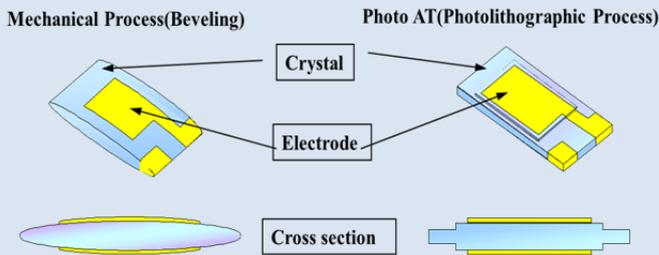
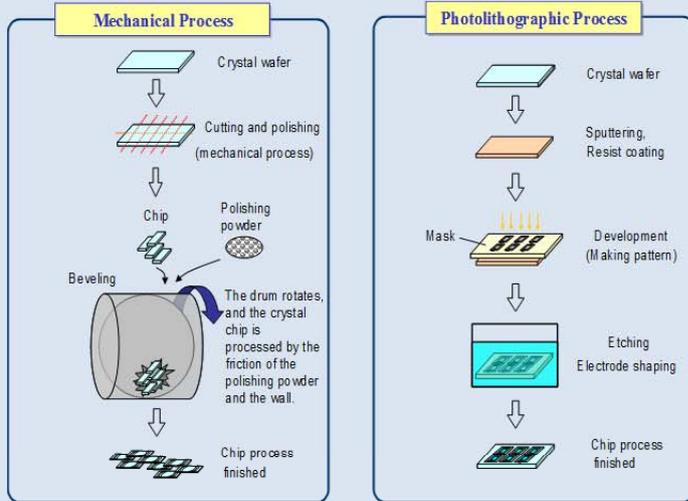
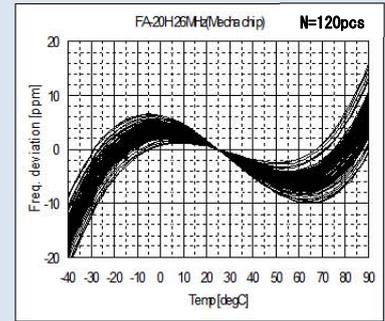
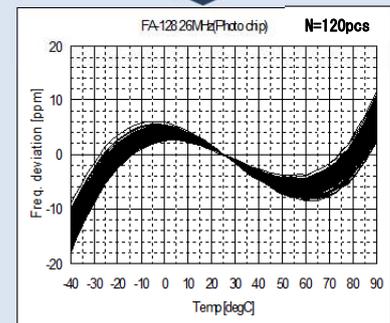


Figure 2. Comparison of crystal chip processing technologies



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 inverted-mesa AT-cut crystals

Epson products that use QMEMS inverted-mesa AT crystal units that oscillate at a high-frequency fundamental include, in the SPXO (simple packaged crystal oscillator) category, the SG-210S\*H and SG-770\*\*\*/SG-771\*\*\* series and, in the VCXO (voltage-controlled crystal oscillator) category, the VG-45\*\*series.

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 crystals, are needed.

Figure 4 shows a comparison of the spurious at 491.52MHz of a VG-4513CB, a VCXO that uses an inverted-mesa AT crystal versus the spurious of an earlier frequency-multiplied Epson product.

Previous Epson product (4x multiplication of 122.88 MHz) VG-4513CB (491.52 MHz fundamental vibration mode)

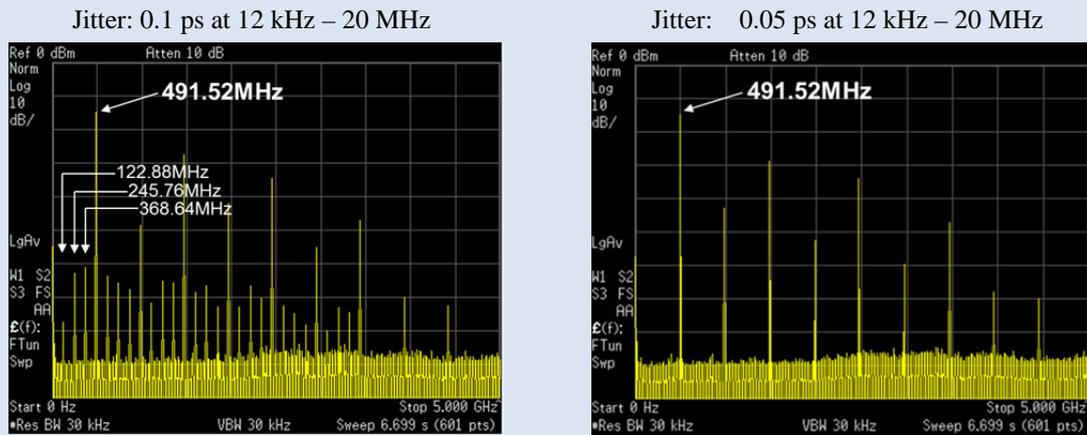


Figure 4. Comparison of spurious characteristics (Spectrum analyzer measurement)

One of the drawbacks of using a PLL circuit or multiplier circuit to obtain high frequency is the deterioration of jitter characteristics due to noise from other sources other than the main signals (spurious). If an inverted-mesa AT crystal is used (Figure 4, right), low jitter can be achieved because the spurious elements are not present as in the earlier products, since the high-frequency oscillation is in the fundamental mode.

The advantages of direct, high-frequency oscillation in the fundamental mode are significant, and inverted-mesa AT crystals are likely to become essential components for the coming built-out of infrastructure.

#### 4. Conclusion

High-frequency reference 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 three-part series of articles, 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) low phase jitter SAW oscillators; and (3) 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 these 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.