Modern crystal processing technology

<u>Crystal process determines frequency control</u>

Accurate frequency control is of paramount importance for reliability and growth of telecommunications. Rather tough demands are set on the performance of crystal oscillators and especially on the resonator. It is the resonator, which to a large extent determines the stability. The requirement on the frequency source in a GSM system is an overall absolute accuracy better than 50 parts per billion (ppb) for the RF frequency generation. The same source is also used for all carriers of a base station transceiver. The stability requirement is even more stringent for the 3rd generation mobile networks that use higher frequency bands and data rates.

Several factors causes insufficient stability of a crystal based frequency source, some of the more important factors such *as long-term stability (aging), phase noise, retrace characteristics, and drive level dependence* can be directly traced to the production process of the crystal itself. These instability factors are described later in this editorial.

<u>Conventional methods inadequate</u>

It can easily be deduced that conventional crystal production methods are no longer adequate to provide the performance and volumes of high performance crystal oscillators that the communications industry requires. True volume production of high-precision crystals demands *improved crystal production techniques.* Traditional crystal production techniques feature unsatisfactorily yields and reproducibility for high precision crystals that result in long lead times.

<u>Redefining high-precision crystal processing</u>

Quartz Pro's innovative solution to the increasing demand from the communications industry is a new modern crystal production process. The patented and fully automated production process allows mass production (more than 20K units per month) of high performance crystals with consistent excellent quality, high yield, short lead times, and delivery precision. In addition, the unique crystal manufacturing process minimizes the effects of aging, phase noise, retrace, and drive level dependence in the crystal, assuring its long-term frequency operation.

The modern way of processing high performance crystals

Quartz crystals are produced automatically in ultra-high vacuum in sealed chambers without contact with the atmosphere or with any human being. It's enough that contaminants reach a few parts per million for crystal quality to be compromised. That's why the atmosphere has been eliminated from the process. But that's not enough. To remove the extremely small contaminants that may remain and that can affect the quality and life span of our crystals, the process includes a series of cleaning steps that reach all the way down to atomic level. The basic principle is that a pure crystal oscillates without degradation.

The production yield of the automated process is more than 90%. Compare this to conventional methods that show a yield between 30 to 70% for high-precision crystals. A high and stable yield means that the right amount can be produced to order without unnecessary delays. And due to the high yield and reproducibility, the number of tests that have to be done and that further decrease delivery times have been reduced.

A solid patent covers the production process, which works fully automatically. Four process steps involve cleaning the surface of the crystals, after which gold electrodes are attached. The whole procedure takes place in an ultra-high vacuum. The pressure varies in the various process steps, but the base pressure is 10E-9 mbar.

The Pre-treatment is done conventionally where the amount of polishing and etching is based on the raw materials, the blanks, and the specification requirements. Before entering the automated process the quartz blanks are mounted.

The first vacuum chamber is then loaded with 1000 crystals. The chamber operates in high vacuum and is heated to over 200 degrees Celsius so that the moisture that has been absorbed in the crystals evaporates.

Chamber number two deals with the organic molecules/hydrocarbons that are attached to the crystal surface. The crystals are cleaned in a hydrocarbon cracking process using ultraviolet light and atomic oxygen. The cracking process breaks down the molecules into smaller parts, which then are removed by a vacuum pump.

In chamber number three; atomic guns etch away the last remnants. The electrodes are sputtered on with a magnetron sputter and the frequency is measured at the same time. The electrode thickness is between 50 and 150 nm and can be adjusted by a few layers of atoms, i.e. a few tenths of a nm. Conventional methods make use of *evaporation* to attach the electrodes.

A crystal resonator is extremely sensitive to asymmetry. *The sputter method* allows for good control of the thickness, which contributes to good symmetry. The stability of the electrodes is one of the major challenges for high performance resonators. A major contributor to electrode instability is residual stress in the metal film that changes with time even at normal operating temperature. Residual stress can be divided into thermally induced stress (mismatch of coefficients of thermal expansion between film and substrate material) and intrinsic stress (related to the microstructure of the film). As the residual stress changes, it leads to a change in frequency and motional parameters. *The sputtering process offers far more ways of controlling the film stress than does evaporation.*

Quartz Pro has performed thorough tests on the residual stress in sputtered gold electrodes with respect to 1) various deposition rates, 2) pressures, 3) deposition temperatures, 4) film thickness, and 5) substrate smoothness. The findings show that there is a decrease in compressive stress at slower deposition rates, increased pressure, higher deposition temperature, thinner film, and smoother substrate.

Finally, in chamber number 4, the crystals are heated again using IR light to minimize residual mechanical stress. This is called annealing (accelerated aging). The initial stress is often *compressive*, but turns *tensile,* after annealing. The crystals are then encapsulated in a strictly controlled environment and finally leak tested, controlled and labeled. All the crystals produced at the same time are practically identical. The full procedure takes between 12 and 48 hours depending on the crystal requirements.

<u>Process technology affects crystal frequency source performance</u>

Some of the more important factors affecting stability of a crystal based frequency sources are *long-term stability (aging), phase noise, retrace characteristics, and drive level dependence*. All these factors are directly related to the quality of the crystal production process.

Long-term stability (aging)

The aging rate is one of the most challenging points in the production process. Extra care in manufacturing the crystal resonator can reduce the effects of aging. Aging of an AT-cut crystal is mainly caused by two factors:

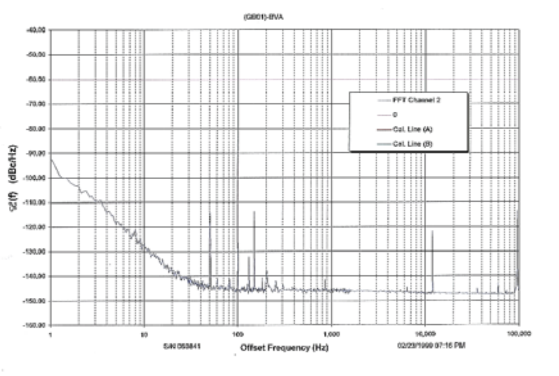
1) Mass changes that is caused by impurities in the crystal material and contamination on the crystal surface

2) Mechanical stresses in the crystal material and the deposited electrodes

A crystal manufacturing process must minimize these factors that cause aging. Contamination control is one of the main issues in the production of high precision crystals. The process must clean the crystals all the way down to atomic level. In the Quartz Pro process, thorough cleaning of both surfaces of the crystal is performed prior to electrode deposition by means of outgassing, UV-ozone cleaning (cracking), and atom bombardment.

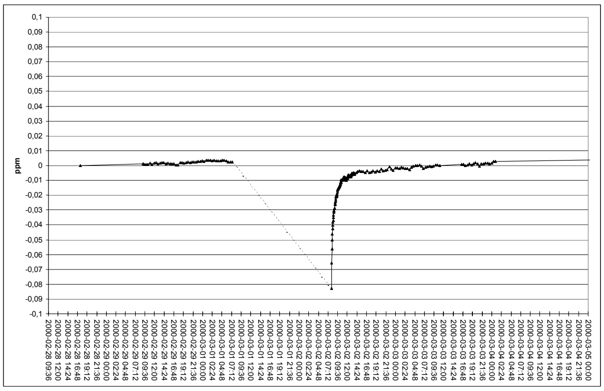
Phase noise

In a properly designed oscillator, the resonator is the primary noise source close to the carrier, and the oscillator circuitry is the primary source far from the carrier. The noise close to the carrier has a strong inverse relationship with resonator Q (quality factor). The crystal Q is directly affected by design and *process technology*.



Retrace characteristics

When an oscillator is turned off and then back on again, it will not resume at the same frequency at which it had been operating. Eventually, the oscillator will begin to age at its previous rate but will most likely be offset slightly from its original frequency. Retrace limits the accuracy achievable with oscillators in applications where it is on-off cycled. The mechanisms that can cause this effect include changes in the quartz resonator, and resonator contamination. The two first factors are minimized by *proper process control.*

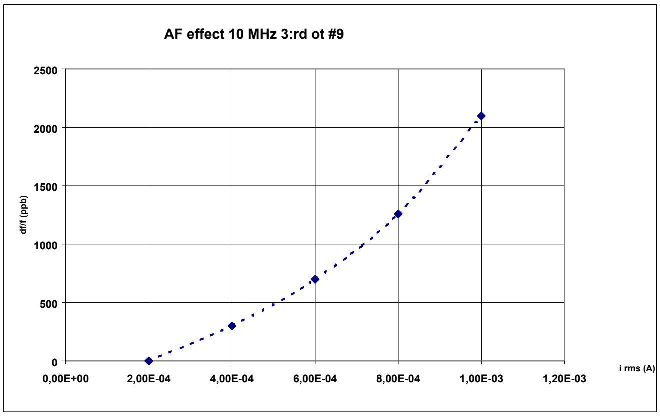


Retrace characteristics

<u>Drive level dependence</u>

A quartz crystal is analogous to a mechanical block. The clock relies on the main spring energy to keep the pendulum going. The crystal requires energy to sustain the mechanical vibration, which in turn maintains the piezoelectric action. The resonating frequency of the oscillator will change with a variation in the drive energy. The frequency of an AT cut crystal will change by 1   10–9 with a variation in drive of one microwatt. The drive level requirements will vary depending upon the crystal impedance.

Excessive drive level may cause the mechanical vibrations to exceed the quartz elastic limits resulting in a fracture. The usual operating point is for minimum amplitude drive level since this is where maximum long-term oscillator stability is achieved, whereas the best short -term stability is achieved at high drive levels. This means that a compromise has to be found. The frequency change with drive level is proportional to the square of the drive current. The coefficient depends on resonator design and *process control*.



Frequency change with drive current

Because of the drive-level dependency of frequency, the highest stability oscillators usually contain some form of automatic level control in order to minimize frequency changes due to oscillator circuitry changes.

Modern process technology for modern components

High-performance crystal frequency sources require a revolution in process technology. The difference may not be visible to the naked eye, but it can be recognized in the different factors that affect frequency stability and therefore the quality of the entire system. True modern crystal processing is automatic thereby eliminating human error, minimizes factors contributing to frequency instability, exhibits high yield, and is able to produce large volumes in short time. All this is necessary to meet the tough demands on performance and volumes posed by the communications industry.

The modern automatic way of producing crystals