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## CHOOSING AN AT OR SC CUT FOR OCXOs

### Introduction

The use of different crystal cuts in frequency control applications result in different performance. This paper will discuss the AT cut and SC cut performance along with cost trade-offs of the two cuts. Since the SC is primarily used for ovenized applications, this will be the focus.

The SC and AT cuts have different temperature stability curves. For comparison purposes, the chart below shows both the AT and SC.

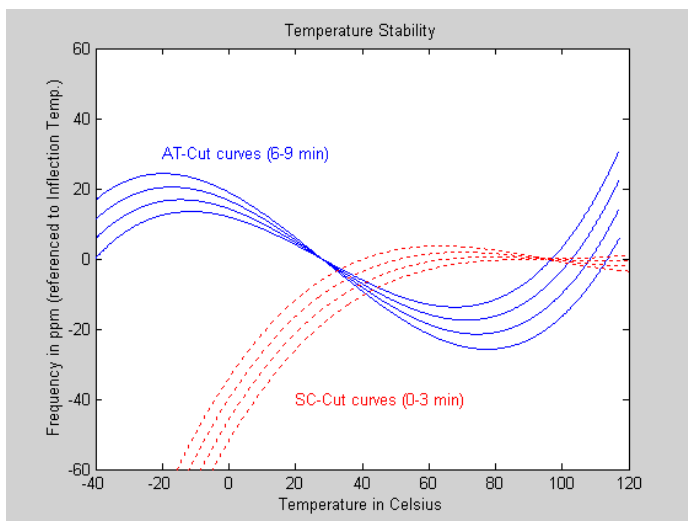


Figure 1

As one can see, the AT is the preferred cut for a wide temperature range. Being symmetrical around 25°C (inflection temperature), angles for good stability over -55°C to 125°C can be produced. SC cuts have an inflection temperature of 92°C and are very flat at the hotter end, but tail off quickly on the cold end. For OCXO applications, the operating temperature for the crystal is usually in the range of 80-100°C.

### AT Cuts

AT cut is the most popular cut angle used in the industry. It has very good performance over a wide temperature range. The cut is made from a Y bar at 35° theta rotation.

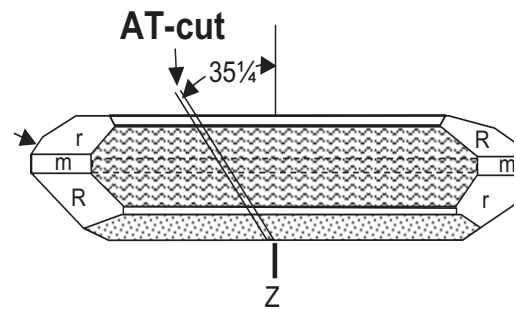


Figure 2

Temperature curves of the AT cut at the upper turning point:

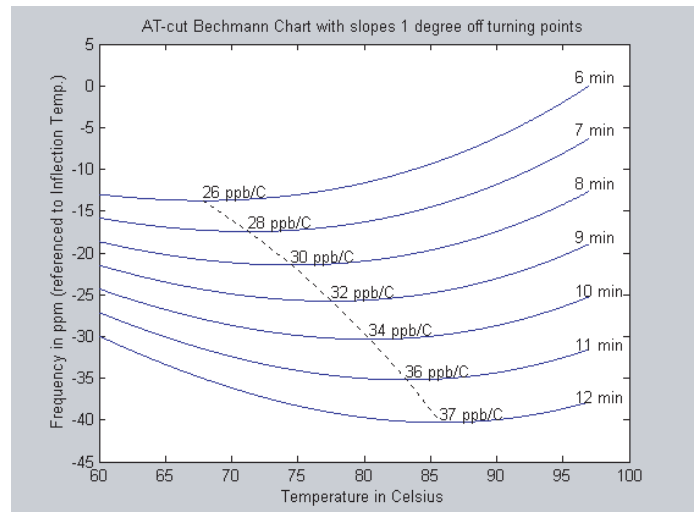


Figure 3

Continued...

In OCXO applications, AT cut angles are defined by a zero slope point or turning point. The slope at the turning point and the oven control are the primary variables of frequency stability.

Oven temperatures are usually set at 10°C over the upper ambient required by the specification. For 0-70°C applications, ovens are set at 85°C +/- 5°C. The turning point angle is specified to match the oven temperature.

In Figure 3, we also show the localized slope of each curve to ±1°C off turning point. This allows the OCXO designer to see expected stability if the oven control is less than ±1°C of the turning point of the AT cut crystal. If the oven can be held tighter, then tighter stability's can be achieved.

### SC Cut

Earl EerNisse defined the SC cut in theory in 1976. Jack Kusters later confirmed it through experiment in 1977 [1]. The cut is a double rotation and defined by theta =34.11 degrees and phi =21.93 degrees.

The letters SC stand for “stress compensated”. Since quartz is anisotropic, the stresses seen in the AT cut can be reduced or eliminated by a second rotation in the phi direction. [2] Through calculations, a phi rotation of 21.93°, would achieve no stress induced frequency shift.

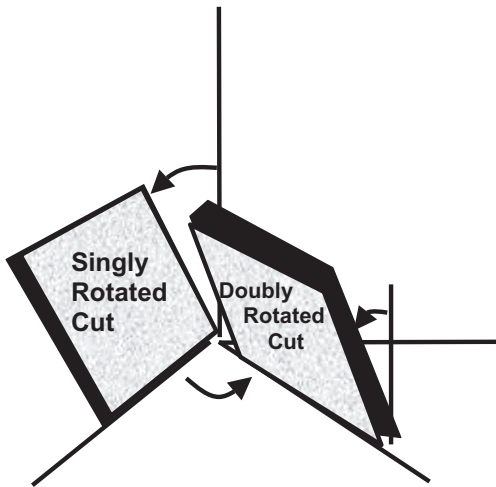


Figure 4

Temperature curves of SC angles at the lower turning point;

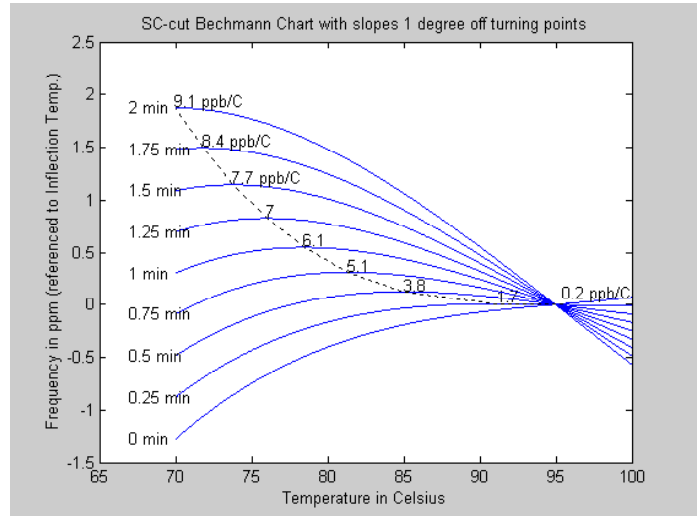


Figure 5

In the SC curves above (theta equivalent), note the localized slope of the curves compared to the AT curves shown earlier. This 5x improvement in slope is one reason why SC cuts are used in tighter stability applications. Also note the tighter angle distribution to achieve tuning points in the typical oven range required by the OCXO.

### SC cut performance improvements

As stated, SC cuts are stress compensates. Reduction in stress effects in a quartz crystal result the following performance improvements [3]:

*Mechanical stress (compression) across the mounts results in less frequency shift. Lower aging.*

Aging in quartz crystal units is always a concern in high stability devices. Stress (compression or tension) on the wafer's edge by the mount, causes the frequency to move negatively. Over time, this stress relaxes and causes frequency to move positively. SC cuts minimize this frequency shift and results in better aging than the AT cut.

*Higher drive levels can heat up the quartz and cause stress in the quartz. SC's allow lower frequency shift during changing drive level.*

Frictional losses in the quartz convert to heat. Localized heat (under the electrode area) sets up thermal gradients and stress in the quartz. More drive equals more heat. This stress causes the frequency to change. SC cuts show a lower frequency shift due to the changes in the drive level.

Continued...

*Oven heat can cause thermal gradients across the quartz. OCXO overshoot will be reduced.*

In the OCXO, the oven is designed to heat the quartz device and keep it at a constant temperature. During the initial warm-up, oven heaters are run at 100% power to shorten the warm-up time. During this time, temperature gradients in the quartz are the worst, resulting in stress in the quartz. Once the oven achieves the set temperature (usually 85°C), the frequency continues to move beyond the set frequency. This is called “overshoot”. As stresses continue to settle out, the frequency will continue to move until temperature gradients (due to the oven) reach equilibrium. SC cuts show much less overshoot than AT cuts.

*Gravitational forces can put stress on the quartz resulting in frequency shift under shock or vibration. Lower G-sensitivity.*

G-sensitivity is important in high stability applications that will see motion while operating. This can be a mobile application such as vehicle or airborne. Or can be specified in any application that will see shock or vibration. Mechanical forces resulting from a change in momentum can affect the frequency stability of an OCXO. This is quantified by the amount of force as “G” (one gravitational force). A minimum delta F per G can be specified for a given application. The changing stress on the quartz in the mounts results in a change in frequency. For SC cuts, specs as tight as tenths of ppb /G can be met. AT cuts are 10x worse. These numbers are seen for one “G”, but if vibration or shock was seen at 10G’s to 1000G’s, the frequency shift should multiply by that amount.

*Oven changes will cause small transients resulting in thermal stress. Lower short term stability.*

In an OCXO oven, oven temperature control is maintained as tight as possible. If outside temperature changes, the oven reacts to compensate for this change. These changes occur quickly and are usually very small but create temperature transients and thermal stress in the quartz. The stress impacts frequency drift. SC cuts react less to this transient, resulting in better short-term stability.

*SC’s can achieve higher Q*

Although not a stress related effect, the SC cuts lower Cm value results in a higher Q in the crystal. Higher Q results in better phase noise in the oscillator, which is very desirable in high stability applications.

## Cost issues

Why are SC cuts so much more expensive than AT cuts?

*Two rotations are more difficult than one.*

The cutting operation is high labor and more difficult to control. With the second rotation (phi), the theta angle is also rotated. If one angle moves, the second angle will also move.

*Angle tolerance for SCs is much tighter than ATs*

Theta angle window is usually 0.7 minutes wide for an SC. The AT angle is about 4.0 minutes wide for similar turning point range of 80-90°C. Tighter angles have more yield loss.

*SC cuts have additional lapping operations*

Due to the extremely tight theta requirement of the SC, wafers are sometimes “angle corrected” after the sawing operation. This added operation improves yields but adds labor cost.

*SCs require vacuum seal enclosures*

SC cuts are pressure sensitive, requiring a vacuum-sealed enclosure to allow lower resistance and highest Q. AT cuts will benefit from vacuum sealing, but SCs almost always require this for proper performance. Vacuum sealing is usually done by coldweld or glass seal, which are more expensive packages.

*SCs require tighter calibration*

The SC cut has a lower Cm value (at a given frequency) vs. an AT cut. This means less frequency pull in the circuit resulting in a tighter calibration requirement. SCs need to be calibrated at least 3x tighter than an equivalent AT cut to allow setting the frequency of oscillator.

*SC oscillators need frequency traps*

SC cut crystals run on the C mode. A second mode that is equally strong, the B mode, must be trapped to avoid the circuit from running on the wrong frequency. This extra circuitry costs more and takes up more space.

*Continued...*

## Summary

We have discussed the differences of AT and SC cut crystals. In OCXO applications, SC cuts result in better temperature stability (<10ppb). SC cuts also can achieve better aging (<2ppb/day). SC cuts have higher Q, which achieve lower phase noise. To achieve these performance gains of the SC, manufacturing costs are higher due to greater labor and poorer yields over the AT cuts.

Performance	SC Cut	AT Cut
Aging	best	good
Temperature Stability	best	good
Drive Level sensitivity	best	good
G Sensitivity	best	good
Frequency Overshoot	best	good
Volume/Availability	good	best
Delivery/lead-time	good	best
Cost	higher	lower

[1] Virgil E. Bottom, *Introduction to Quartz Crystal Unit Design*, pg 222, Van Nostrand Reinhold Company, 1982

[2] Earl EerNisse and John Kusters, *Orientation Dependence of "True" SC-Cuts*, 44th Annual Symposium on Frequency Control, 1990

[3] John Vig, "Quartz Crystal Resonators and Oscillators For Frequency Control and Timing Applications, A Tutorial", July 2001

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