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Quartz Crystal Basic Theory

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What is “Quartz”?

The technical formula is SiO_2 and is the major constituent in many rocks and sand. The crystalline form of SiO_2 or quartz is relatively abundant in nature, but in the highly pure form required for the manufacture of quartz crystal units, the supply tends to be small. The limited supply and the high cost of natural quartz have resulted in the development of a synthetic quartz manufacturing industry. The synthetic quartz manufacturing technology turns quartz crystals an indispensable component of modern electronic production.

What is the "Quartz Crystal Units"?

Quartz units consist of a piece of piezoelectric material precisely dimensioned and orientated with respect to the crystallographic axes. This wafer (also called plate or blank) has one or more pairs of conductive electrodes, formed by vacuum evaporation. When an electric field is applied between the electrodes the piezoelectric effect excites the wafer into mechanical vibration.

Quartz crystal units (often called crystal resonators) are widely used in frequency control applications because of their unequalled combination of high Q, stability, small size and low cost. Many different substances have been investigated as possible resonator materials, but for many years quartz units have been preferred in satisfying needs for precise frequency control. Compared to other resonators, for example, LC circuits, mechanical resonators such as tuning forks, and piezoelectric ceramic resonators based or other single-crystal materials, the quartz unit has an unique combination of properties.

First, the material properties of single-crystal quartz are extremely stable with time, temperature, and other environmental changes, as well as highly repeatable from one specimen to another. The acoustic loss or internal friction of quartz is very low, which results in a quartz unit having an extremely high Q-factor. The intrinsic Q of quartz is about 10^7 at 1 MHz. Mounted resonators typically have Q factors ranging from tens of thousands to several hundred thousand, which is orders of magnitude better than the best LC circuits.

The second key property of the quartz unit is its stability with respect to temperature variation. Depending on the shape and orientation of the crystal blank, many different modes of vibration can be used and it is possible to control the frequency-temperature characteristics of the quartz resonator to within close limits by an appropriate choice. The most commonly used type of resonator is the AT-cut, where the quartz blank is in the form of thin plate cut as an angle of about 35°15' to the optic axis of the crystal.

The third essential characteristic of the quartz unit is related to the stability of its mechanical properties. Short and long term stabilities manifested in frequency drifts of only a few parts per million per year are readily available from commercial units. Precision crystal units manufactured under closely controlled conditions are second only to atomic clocks in the frequency stability and precision achieved.

How Piezoelectricity Works for "Quartz Unit"?

The word piezo-electricity takes its name from the Greek piezein "to press", which literally means pressure electricity. Certain classes of piezoelectric materials will in general react to any mechanical stresses by producing an electrical charge. In a piezoelectric medium the strain or the displacement depends linearly on both the stress and the field. The converse effect also exists, whereby a mechanical strain is produced in the crystal by a polarising electric field. This is the basic effect which produces the vibration of a quartz crystal.

What Makes Optimal Angle of Cut So Important?

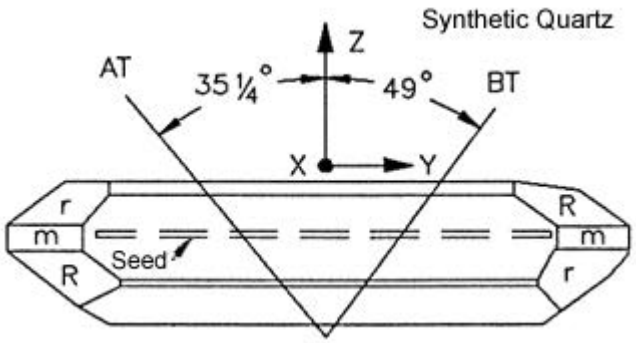

Figure-1 - Quartz - Optimal Angle Cut

The right schematic diagram (Figure-1) is a cultured quartz crystal grown from a Y-oriented seed crystal for use in fabricating AT-cut resonators. A seed crystal establishes the initial crystal orientation and encourages growth in the Y direction at the expense of the Z-axis. Seed crystals are carefully selected by Token to avoid defects which might propagate as the crystal grows. The position of the seed crystal is indicated. The lines sloping left from the x-axis mark the saw cut position for AT plates, the line sloping to the right indicates the BT-cut. In practice, these angles are very critical and are precisely determined using Bragg diffraction (also referred to as the Bragg formulation of X-ray diffraction).

The AT-cut characteristic is the most commonly used type of resonator. It has a frequency temperature coefficient described by a cubic function of temperature, which can be precisely controlled by small variations in the angle of cut. This cubic behavior is in contrast to most other crystal cuts which give a parabolic temperature characteristic. It makes the AT-cut well suited to applications requiring a high degree of frequency stability over wide temperature ranges. Other important characteristics are aging and quality factor Q.

Vibration Modes

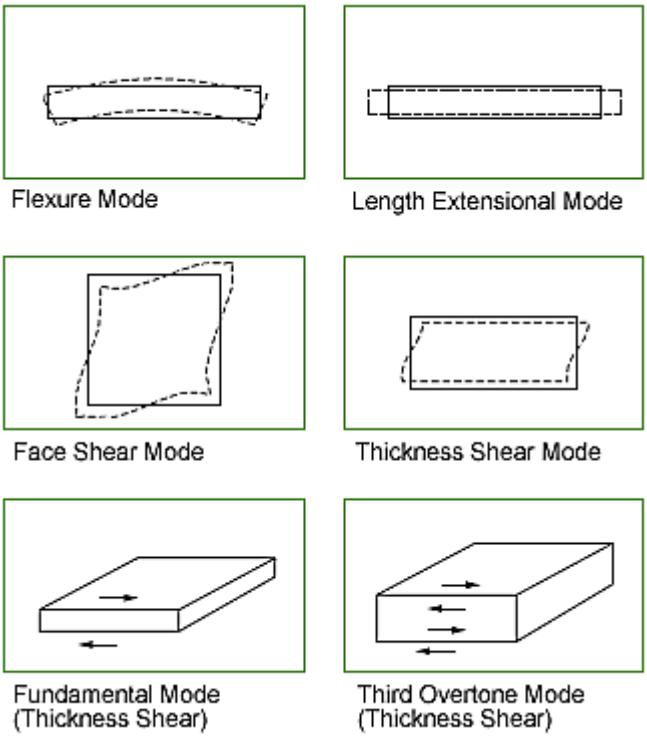

Figure-2 - **Mode of Vibration**

The AT-cut resonator uses the thickness shear mode of vibration (Figure-2). A standing wave is set up in the crystal blank by the reflection at both major surfaces of traverse waves travelling in the thickness direction. The major mechanical displacement is in the plane of the crystal at right angles to the direction of wave propagation. At resonance an odd number of half wave lengths are contained in the thickness plane of the crystal blank. Therefore the thickness is the primary frequency determining dimension.

The AT-cut is commonly manufactured in the frequency ranges:

- 1 MHz ~ 32 MHz as Fundamental Mode
- 30 MHz ~ 250 MHz as Overtone Mode (3rd; 5th; 7th; 9th)

Below about 1 MHz the thickness shear mode resonators become too cumbersome and clumsy for general use and other modes of vibrations are used:

- below about 100 KHz Flexural Mode, Length Extensional Mode
- 100 KHz Face Shear Mode (CT-Cut; DT-Cut; SL-Cut)

For each mode of vibration there is an optimal angle of cut which controls the frequency deviation of the quartz crystal over the temperature range.