Quartz clocks and **quartz watches** are timepieces that use an electronic oscillator regulated by a quartz crystal to keep time. This crystal oscillator creates a signal with very precise frequency, so that quartz clocks and watches are at least an order of magnitude more accurate than mechanical clocks. Generally, some form of digital logic counts the cycles of this signal and provides a numerical time display, usually in units of hours, minutes, and seconds.

Since the 1980s, when the advent of solid-state digital electronics allowed them to be made compact and inexpensive, quartz timekeepers have become the world's most widely used timekeeping technology, used in most clocks and watches as well as computers and other appliances that keep time.

Explanation

Chemically, quartz is a specific form of a compound called silicon dioxide. Many materials can be formed into plates that will resonate. However, quartz is also a piezoelectric material: that is, when a quartz crystal is subject to mechanical stress, such as bending, it accumulates electrical charge across some planes. In a reverse effect, if charges are placed across the crystal plane, quartz crystals will bend. Since quartz can be directly driven (to flex) by an electric signal, no additional transducer is required to use it in a resonator. Similar crystals are used in low-end phonograph cartridges: The movement of the stylus (needle) flexes a quartz crystal, which produces a small voltage, which is amplified and played through speakers. Quartz microphones are still available, though not common.[*citation needed*]

Quartz has a further advantage in that its size does not change much as temperature fluctuates. Fused quartz is often used for laboratory equipment that must not change shape along with the temperature. A quartz plate's resonance frequency, based on its size, will not significantly rise or fall. Similarly, since its resonator does not change shape, a quartz clock will remain relatively accurate as the temperature changes.

In the early 20th century, radio engineers sought a precise, stable source of radio frequencies and started at first with steel resonators. However, when Walter Guyton Cady found in early 1920s that quartz can resonate with less equipment and better temperature stability, steel resonators disappeared within a few years. Later, scientists at National Institute of Standards and Technology (then the U.S. National Bureau of Standards) discovered that a crystal oscillator could be more accurate than a pendulum clock.

The electronic circuit is an oscillator, an amplifier whose output passes through the quartz resonator. The resonator acts as an electronic filter, eliminating all but the single frequency of interest. The output of the resonator feeds back to the input of the amplifier, and the resonator assures that the oscillator runs at the exact frequency of interest. When the circuit is powered up, a single burst of shot noise (always present in electronic circuits) can cascade to bringing the oscillator into oscillation at the desired frequency. If the amplifier were perfectly noise-free, the oscillator would not start.

The frequency at which the crystal oscillates depends on its shape, size, and the crystal plane on which the quartz is cut. The positions at which electrodes are placed can slightly change the tuning as well. If the crystal is accurately shaped and positioned, it will oscillate at a desired frequency. In nearly all quartz watches, the frequency is 32768 Hz,[1] and the crystal is cut in a small tuning fork shape on a particular crystal plane.[2] This frequency is a power of two (32768 = 2^{15}), just high enough to exceed the human hearing range, yet low enough to keep electric energy consumption, cost and size at a modest level and to permit inexpensive counters to derive a 1-second pulse.[3] The data line output from such a quartz resonator goes high and low 32768 times a second. This is fed into a flip-flop (which is essentially two transistors with a bit of cross-connection) which changes from low to high, or vice versa, whenever the line from the crystal goes from high to low. The output from that is fed into a second flip-flop, and so on through a chain of 15 flip-flops, each of which acts as an effective power of 2 frequency divider by dividing the frequency of the input signal by 2. The result is a 15-bit binary digital counter driven by the frequency that will overflow once per second, creating a digital pulse once per second. The pulse-per-second output can be used to drive many kinds of clocks. In analog quartz clocks and wristwatches, the electric pulse-per-second output is nearly always transferred to a Lavet-type stepping motor that converts the electronic input pulses from the flip-flops counting unit into mechanical output that can be used to move hands.

It is also possible for quartz clocks and watches to have their quartz crystal oscillate at a higher frequency than 32768 (= 2^{15}) Hz (high frequency quartz movements[4]) and/or generate digital pulses more than once per second, to drive a stepping motor powered second hand at a higher power of 2 than once every second,[5] but the electric energy consumption (drain on the battery) goes up because higher oscillation frequencies and any activation of the stepping motor costs energy, making such small battery powered quartz watch movements relatively rare. Some analog quartz clocks feature a sweep second hand moved by a non-stepped battery or mains powered electric motor, often resulting in reduced mechanical output noise.

History

Four precision 100 kHz quartz oscillators at the US Bureau of Standards (now NIST) that became the first quartz frequency standard for the United States in 1929. Kept in temperature-controlled ovens to prevent frequency drift due to thermal expansion or contraction of the large quartz resonators (mounted under the glass domes on top of the units) they achieved accuracy of 10^{-7}, roughly 1 second error in 4 months.

The piezoelectric properties of quartz were discovered by Jacques and Pierre Curie in 1880. The vacuum tube oscillator was invented in 1912.[31] An electrical oscillator was first used to sustain the motion of a tuning fork by the British physicist William Eccles in 1919;[32] his achievement removed much of the damping associated with mechanical devices and maximised the stability of the vibration's frequency.[32] The first quartz crystal oscillator was built by Walter G. Cady in 1921. In 1923, D. W. Dye at the National Physical Laboratory in the UK and Warren Marrison at Bell Telephone Laboratories produced sequences of precision time signals with quartz oscillators.

In October 1927 the first quartz clock was described and built by Joseph W. Horton and Warren A. Marrison at Bell Telephone Laboratories.[33][note 1][35][36] The 1927 clock used a block of crystal, stimulated by electricity, to produce pulses at a frequency of 50,000 cycles per second.[37]

A submultiple controlled frequency generator then divided this down to a usable, regular pulse that drove a synchronous motor.[37]

The next 3 decades saw the development of quartz clocks as precision time standards in laboratory settings; the bulky delicate counting electronics, built with vacuum tubes, limited their use elsewhere. In 1932 a quartz clock was able to measure tiny variations in the rotation rate of the Earth over periods as short as a few weeks.[38] In Japan in 1932, Issac Koga developed a crystal cut that gave an oscillation frequency with greatly reduced temperature dependence.[39][40][41] The National Bureau of Standards (now NIST) based the time standard of the US on quartz clocks between the 1930s and the 1960s, after which it transitioned to atomic clocks.[42] The wider use of quartz clock technology had to await the development of cheap semiconductor digital logic in the 1960s. The revised 1929 14th edition of *Encyclopædia Britannica* stated that quartz clocks would probably never be affordable enough to be used domestically.[*citation needed*]

Their inherent physical and chemical stability and accuracy has resulted in the subsequent proliferation, and since the 1940s they have formed the basis for precision measurements of time and frequency worldwide.[43]

Developing quartz clocks for the consumer market took place during the 1960's. One of the first successes was a portable quartz clock called the *Seiko Crystal Chronometer QC-951*. This portable clock was used as a backup timer for marathon events in the 1964 Summer Olympics in Tokyo.[44] In 1966, prototypes of the world's first quartz pocket watch were unveiled by Seiko and Longines in the Neuchâtel Observatory's 1966 competition.[45] In 1967, both the CEH and Seiko presented prototypes of quartz wristwatches to the Neuchâtel Observatory competition.[44][46] The world's first prototype analog quartz wristwatches were revealed in 1967: the Beta 1 revealed by the Centre Electronique Horloger (CEH) in Neuchâtel Switzerland,[47][48] and the prototype of the Astron revealed by Seiko in Japan (Seiko had been working on quartz clocks since 1958).[47][44][45][49] The first Swiss quartz watch – the Ebauches SA Beta 21 – arrived at the 1970 Basel Fair.[45][50] In December 1969, Seiko produced the world's first commercial quartz wristwatch, the Seiko-Quartz Astron 35SQ [51][52] which is now honored with IEEE Milestone.[53][54] The Astron had a quartz oscillator with a frequency of 8,192 Hz and was accurate to 0.2 seconds per day, 5 seconds per month, or 1 minute per year. The Astron was released less than a year prior to the introduction of the Swiss Beta 21, which was developed by 16 Swiss Watch manufacturers and used by Rolex, Patek and Omega in their electroquartz models. The inherent accuracy and low cost of production has resulted in the proliferation of quartz clocks and watches since that time.

During the 1970s, the introduction of metal–oxide–semiconductor (MOS) integrated circuits allowed a 12-month battery life from a single coin cell when driving either a mechanical Lavet-type stepping motor, a smooth sweeping non-stepping motor, or a liquid-crystal display (in an LCD digital watch). Light-emitting diode (LED) displays for watches have become rare due to their comparatively high battery consumption. In laboratory settings atomic clocks had replaced quartz clocks as the basis for precision measurements of time and frequency, resulting in International Atomic Time.

By the 1980s, quartz technology had taken over applications such as kitchen timers, alarm clocks, bank vault time locks, and time fuzes on munitions, from earlier mechanical balance wheel movements, an upheaval known in watchmaking as the quartz crisis.

Quartz timepieces have dominated the wristwatch and domestic clock market since the 1980s. Because of the high Q factor and low temperature coefficient of the quartz crystal, they are more accurate than the best mechanical timepieces, and the elimination of all moving parts makes them more rugged and eliminates the need for periodic maintenance.

Commercial analog and digital wall clocks became available in 2014 that utilize a double oven quartz oscillator, accurate to 0.2 ppb. Standard 'Watch' or Real-time clock (RTC) crystal units have become cheap mass-produced items on the electronic parts market.[55]