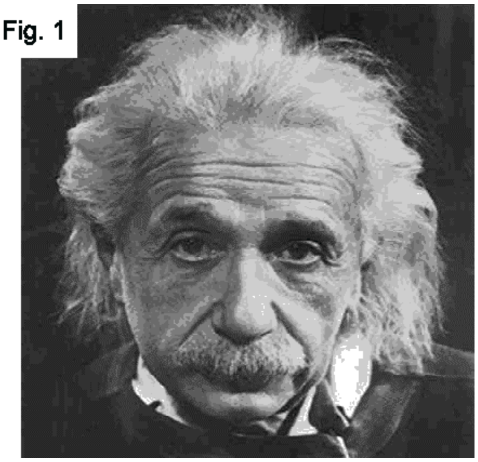
TIME KEEPING WITH QUARTZ CRYSTALS

Fig. 1



"*The only reason for time is so that everything doesn't happen at once*" said Albert Einstein (Fig. 1). One can only assume he wasn't talking about synchronised global networks when he made this statement.

Time is more important than oscillator frequency if events must happen synchronously. The frequency and accuracy of the oscillators generating the 'timing' is not critical so long as they all know exactly what time it is. If, on the other hand, the oscillator generating the timing cannot synchronise itself to a reference timing source then the accuracy of the oscillator's frequency generating the time is now vitally important. The internationally recognised time standard is UTC (Coordinated Universal Time) and is maintained by the National Institute of Standards and Technology, a branch of the United States Department of Commerce.

In Telecoms infrastructure the various levels of required timing accuracies are defined as Stratum levels 1 to 4. The most accurate, and hence the Primary Reference Source is Stratum 1, an atomic clock (Caesium Beam or Hydrogen Maser) which maintains its frequency to an accuracy of $<1x10^{-11}$ for life. The next level, Stratum 2, maintains its frequency to an accuracy of $<1x10^{-10}$ per day with Stratum 3 maintaining its frequency to an accuracy of $<3.7x10^{-7}$ per day. Stratum level 2 is implemented with a precision OCXO (Oven Controlled Crystal Oscillator) using a SC cut crystal. Stratum level 3 is implemented with a precision TCXO (Temperature Compensated Crystal Oscillator) using an AT cut crystal.

So how do these stabilities relate to time? One year is ~365 days x 24 hours x 60 minutes x 60 seconds = 31,536,000 seconds. If the oscillator maintaining the time of a clock had an accuracy of $1x10^{-6}$ per year ($1x10^{-6}$ is 1 ppm [part per million]) then the clock would gain (or lose) 31.536 seconds per year. This makes the atomic clock in the example above accurate to within 0.006 seconds for a 20 year life, the OCXO to within 0.00009 seconds per day and the TCXO to within 0.032 seconds per day.

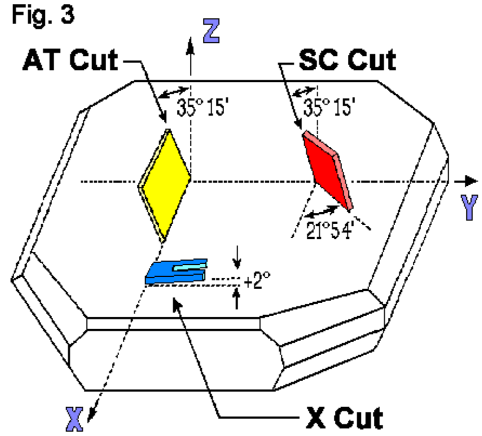
Fig. 2

Most references to Timekeeping, however, refer to 'time of day' rather than data synchronisation and in particular the time of day as displayed on a watch or clock. The first Quartz Clock was built by Warren Marrison and J.W. Horton at Bell Telephone Laboratories in 1927. The first commercially available wrist watch using a Quartz Crystal as the timing element was the 35SQ Astron Watch manufactured by Seiko and launched on Christmas Day in 1969 (Fig. 2). This used an 8.192kHz X cut tuning fork crystal.

Geoff Trudgen RAKON UK Ltd July 2009

All of the different cuts of Quartz Crystal come from the same cultured quartz bar but are cut at different angles to the crystallographic axis (Fig. 3). They each have different mechanical and electrical properties tailored to the final application.

Fig. 3



The AT Cut is used in the majority of crystal oscillators and is particularly suitable for precision TCXO's, with the SC Cut crystal being used primarily in OCXO's.

The X Cut tuning fork crystal (Fig. 4) is used in 'Time of Day' Timekeeping applications (wrist watches, domestic clocks etc.) because of it's natural low frequency of oscillation, very low operating power requirements and low temperature coefficient around 25°C (Fig. 5). In particular the X Cut tuning fork crystal can be made to oscillate at 32.768kHz which, when digitally divided down by 2^{15}, generates a 1 second square wave, ideal for Timekeeping. This same 1 second square wave could be generated by dividing down a 16.777216MHz AT Cut crystal oscillator by 2^{24} but the increase in power consumption due to the higher frequency and additional dividers could be over 100 times that of the X Cut tuning fork crystal option (not ideal for battery powered applications).

Fig. 4

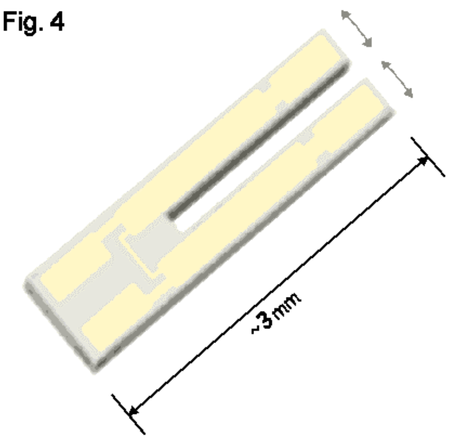
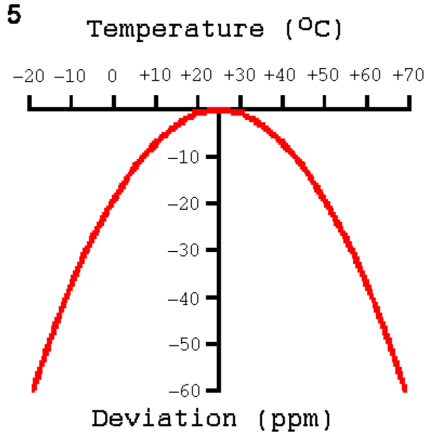


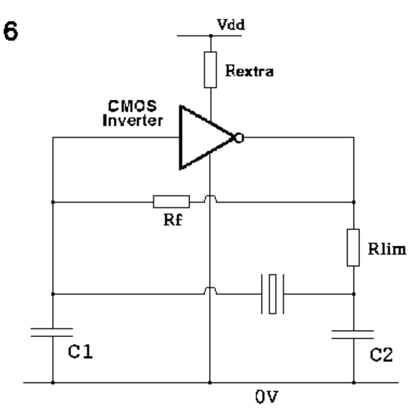
Fig. 5



As Timekeeping involves counting and dividing the usual oscillator of choice is the Gated Pierce (as described in the article 'IC CRYSTAL OSCILLATOR CIRCUITS') but with the added constraint of very low crystal drive power and (usually) low Vdd voltage for battery applications.

A typical 32.768kHz X Cut tuning fork crystal will have an ESR (Equivalent Series Resistance) of 30kΩ to 60kΩ, require a load capacitance of 6pF to 15pF (12.5pF being typical), have 1st year ageing of less than ±3ppm, but more importantly have a maximum crystal drive level of 1µW. The circuit in Fig.6, using an Un-Buffered inverter, will give acceptable performance with the following circuit values. C1=10pF, C2=22pF, Rlim=330kΩ, and Rf=22MΩ. Rextra can be used to limit the current drawn by the Un-Buffered inverter during switching, a value of 47kΩ with Vdd=2V should limit the current consumption to about 5µA.

Fig. 6



Geoff Trudgen RAKON UK Ltd July 2009