SEIKO TWIN QUARTZ

(from: https://forums.watchuseek.com/f9/thermocompensation-methods-movements-2087.html)

In the dual crystal method, one of the crystals is the standard 32 kHz frequency, and one of the crystals is a higher frequency. In the enthusiast fora/literature, one will sometimes hear that the higher frequency crystal 'disciplines' the lower frequency crystal. This should not be taken to mean that the higher frequency crystal is correct in an absolute sense. (In other words, that it does not vary with temperature. Indeed, if this were the case, one would wonder what the role of the lower frequency oscillator was. For the dual crystal movements that we are aware of, the high frequency oscillator is well below one MHz, which means that it cannot be of the AT or similar cuts, and will therefore vary with temperature too.) So, how *do* they work? In a nutshell, while both crystals vary with temperature, they vary *differently*. For any given temperature, there is a unique difference in the frequencies of the two crystals. As such, the frequency difference is effectively a measure of the temperature, and can be used as input to the compensation circuitry. Let's make this more concrete by examining an older dual crystal method used by the caliber 9923A movement in the Seiko Twin Quartz. This method is described in reference 9, from which the following figure was borrowed:

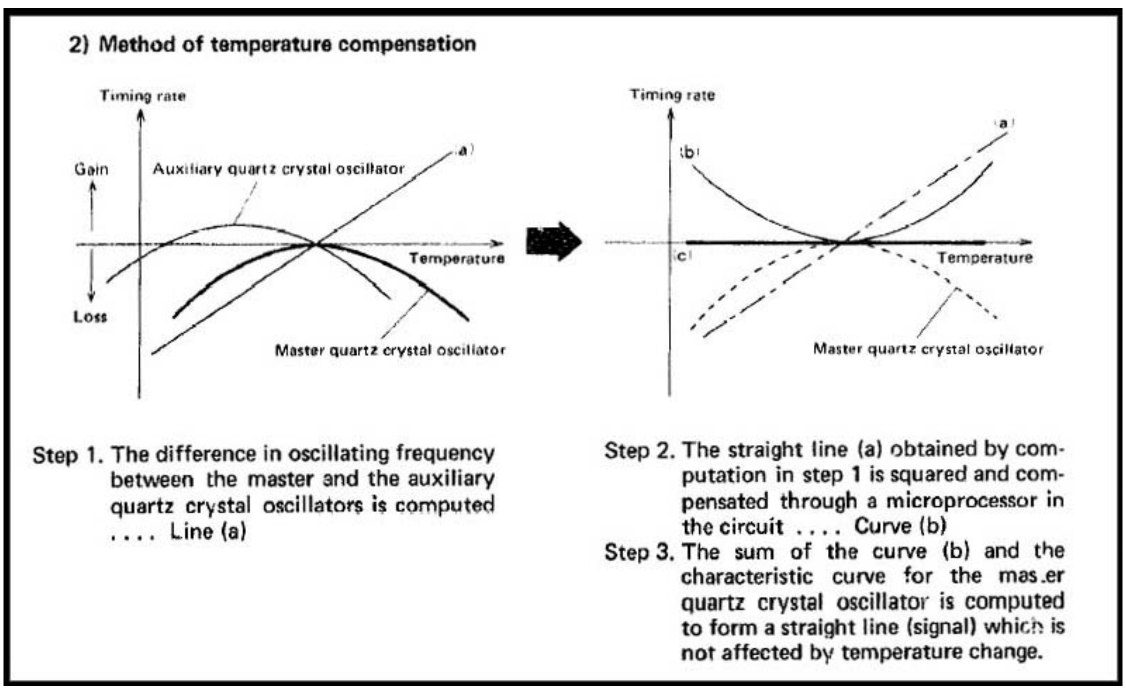

Figure 11: Seiko Twin Quartz dual frequency thermocompensation method. (From Seiko Technical Guide for Caliber 9923A.)

In Figure 11, the 'master quartz crystal oscillator' curve shows how the rate of the 32 kHz crystal varies with temperature. The 'auxiliary quartz crystal oscillator' curve shows how the rate of the high frequency crystal varies with temperature. The high frequency crystal was chosen so that its curve is shaped the same as that of the 32 kHz crystal (both are parabolas with the same quadratic coefficient), but its peak is at a different temperature. Subtracting the two curves yields a straight line, which is denoted as line a in the right plot of the figure. Line a is effectively a measure of temperature. As is indicated in the figure, line a is then digitally transformed into curve b, which is the compensation curve. Because compensation curve b mirrors the master quartz crystal oscillator curve, summing the two yields line c (shown in the right plot), which is a rate that does not vary with temperature. Note that this is essentially a digital count adjustment method: temperature is measured (via the frequency difference of the two crystals), and the count from the 32 kHz crystal is then adjusted based on this temperature. The method of inferring temperature in this technique is quite clever in that it is inherently digital, and so immune to the kind of drift that might occur with an analog temperature sensor. Also, the digital processing is advanced for a movement designed in the mid seventies.

The other notable dual crystal movement is the *ETA 255.561*, which was first used in the Longines Conquest VHP (the older, non perpetual VHP). We have less information about this movement. Fundamentally, though, it undoubtedly works by the same method -- i.e., it uses the frequency difference of the two crystals to determine temperature (implicitly or explicitly), and uses this temperature signal as input to their correction electronics. Because this movement was designed a decade later than the Twin Quartz, substantially more sophisticated digital electronics were available to the designers. This allowed them to move towards a more fully digital system. For instance, they chose digital rate trimming as opposed to the analog trimmer condenser used in the Twin Quartz. It's possible that they incorporated other digitally enabled improvements as well, such as more sophisticated methods of determining how many compensation counts are needed, which would enable more exact compensation of the temperature curve of the 32 kHz crystal. Also, they may not have felt constrained to use a higher frequency crystal whose temperature curve was the same as the lower frequency crystal. (Choosing a cut that was *more* temperature dependent would yield an enhanced, albeit nonlinear, temperature signal.) These last two comments are speculation, however. Beyond broad strokes, we actually know rather little about the details of the thermocompensation method used in this movement, and we would greatly appreciate any information on same from other enthusiasts. Figure 12 shows a nice example of a watch with this movement:

Figure 12: Krieger Marine Chronometer (Photos by Walt Arnstein. Used with permission.)

These are the thermocompensation methods used in watches that we know of. It is very possible, however, that our list is incomplete. A number of watches remain veiled in mystery. Citizen's A660 movement used in their 'The Citizen' models -- the current front runner in specified performance among watches -- is a prime example, as is the Seiko 9F movement. Also, one of us (Bruce) has seen a number of patents for thermocompensation methods that are entirely different than those described above. Among these was a composite crystal with multiple crystal orientations. Another was for a three tined crystal that combined torsional with flexure modes. Most of these alternative patents are from the early eighties. We suspect that they are a product of the early ferment in quartz watch technology, and have not survived to this day. Still, it's possible that these or other methods are still in use.

As clever as these methods are, we are unaware of them approaching fundamental performance limits of quartz. Laboratory quartz oscillators are stable to 0.01 seconds per year or better. While the design constraints for watches (power, size, etc.) are more severe, it's not obvious why, with sufficient ingenuity, thermocompensated watches couldn't be improved from their current best of under five seconds per year to less than 1 second (or even 0.1 seconds) per year. One obvious path would be to pair AT cut crystals with active thermocompensation of the digital count adjustment variety. There may be other, more subtle paths as well. Sadly for us techno-obsessive watch hobbyists, there is no market demand for such next generation movements. (Frankly, there is little demand for even the current generation of thermocompensated quartz watches, which is why they are such rare beasts.) There is hope, though. Other applications such as wireless communications will drive development of higher performance standalone timekeeping methods that are low cost and portable. Quartz might be a viable contender, along with Chip Scale Atomic Clocks and possibly other technologies. We can only hope that, whatever the winning technology, there is some trickle down to our beloved watches.