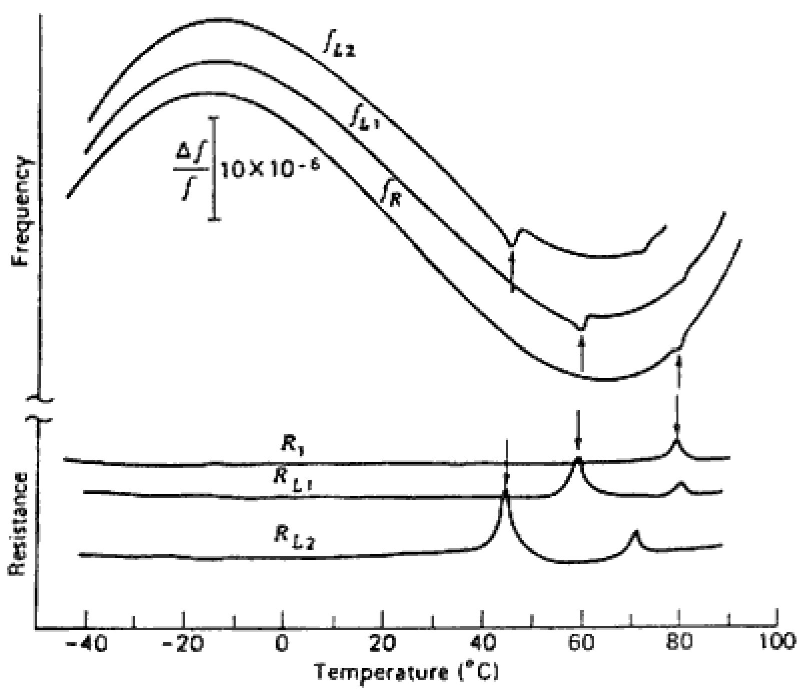
Frequency Perturbations, Coupled Modes or Activity Dips

There are many different types of modes that can be excited during resonance apart from the desired thickness shear mode. Coupled modes, often referred to as 'activity dips', occur when two or more excited modes, or normally their harmonics, beat together. Face-shear, flexure, thickness-twist and many other modes with their respective harmonics, can couple into the main mode at a particular temperature and de-Q the crystal. Hence the term 'activity dip'.

Accompanying the activity dip is a frequency deviation from the smooth temperature characteristic curve. As well as a large change in frequency, in extreme cases, the resistance change can cause oscillation to stop. These dips are much more common on the fundamental modes and where the diameter or size of the crystal is small.

Figure 1:



In spread spectrum digital radios, these activity dips can have adverse effects to the signal processing. For example in GPS receivers, frequency acceleration induced by coupled modes has two main effects. This effect depends on the shape of the coupled mode and the rate of temperature change. Firstly, the frequency shift is interpreted by the GPS as velocity change and therefore produces velocity error; secondly if the frequency acceleration is high enough the system will lose lock on the satellites.

There are two main considerations for the coupled mode: amplitude and gradient. This can be specified as peak-peak ppm and ppm/°C. With Rakon (VC)TCXO these are specified as 'Frequency perturbations' and 'Frequency slope'. For Crystals the "Frequency perturbations" specification is given only as the slope becomes steep over wide temperature ranges.

The maximum amplitude and gradient tolerable to any system will depend on the type of chipset, software and system application. With GPS receivers they can track frequency acceleration to some level but are limited by their carrier-tracking loop. Their sensitivity depends upon loop type, order and bandwidth.

Crystal manufacturers can minimize the occurrence of these dips by optimizing the crystal's design, however to eliminate them completely in production is virtually impossible. Even the best crystal designs still have some percentage of units that have activity dips. This means to supply crystals without frequency perturbations, each unit needs testing. Testing the units in an environmental chamber over the operating temperature range, and looking for frequency perturbations is the most effective method.

Some activity dips can occur over a very narrow temperature span and will have the worst effect. This is when the measurement resolution of the screening system becomes of prime importance, as dips can be easily missed. As shown in the example below, the curve fit line (labelled 'Poly') between the static temperature test points does not show the true result as seen in the ramp plot (Ramp).

Figure 2:

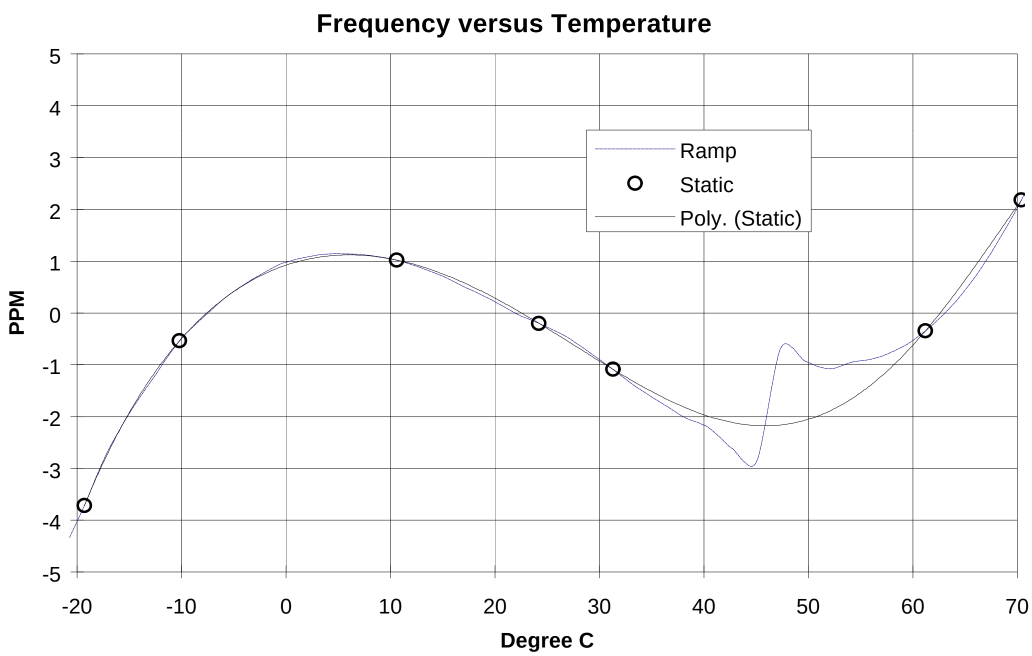


Figure 2 is a crystal in an uncompensated oscillator. Activity dips are apparent in TCXO's as well, seen in Figure 3 & Figure 4 below. The black line is the curve fit between the static test points (circled). The purple line is the high-resolution readings that clearly identify the activity dips.

Figure 3:

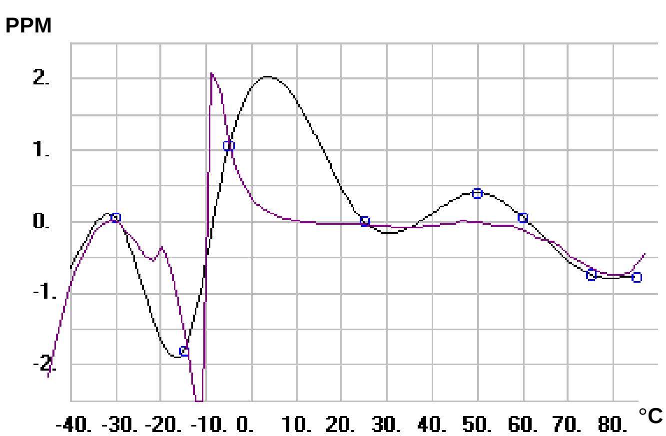
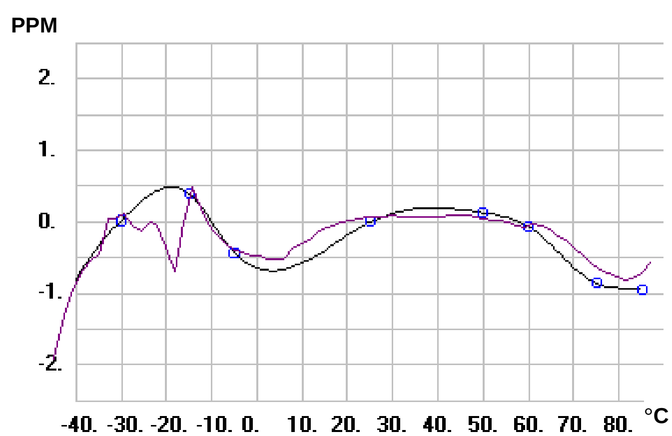


Figure 4:



Rakon has developed a high volume crystal/TCXO temperature test system. This system can screen out these perturbations to a specified slope in frequency shift per degree, as well as specifying the amplitude of the perturbation. Most commercial crystal temperature test systems can only measure the frequency at 5 to 10 points efficiently and then curve fit in between the points. Frequency readings between these points are then unknown. This is because to take measurements, crystals are mechanically switched from unit to unit once the test lot has been stabilised at the pre-determined temperature points.

Rakon's test system on the other hand is a proprietary developed, solid-state switching and measurement system. It is capable of making high speed, high-resolution measurements. The resolution tested depends on the frequency perturbation and slope specification.

Rakon tests all production (100%) through these high-resolution test systems.

Below is an example of frequency perturbations that Rakon has tested in other crystal manufacturers' product. These units were supplied into a GPS application and caused major problems for the GPS manufacturer.

Figure 5: