Rakon's Unique TCXOs for Small Cells

Application Notes

Introduction

The small cell market is gearing up to support the growing need for coverage and ever increasing mobile broadband traffic. With respect to synchronisation requirements, the specifications for 3GPP air interface standards and relevant network interface standards need to be met, depending on the timing architecture. The quality synchronisation is critical for the operation of the wireless access points over various operating conditions and over the life time of the equipment. While the technical requirements for small cells – the scaled mobile base station – remain identical to that of a macro base station, the cost structure of small cell equipment is very lean.

While cost is a key element in the selection of components, long term operation of the equipment in specified environmental conditions is critical for a telecommunication device. This paper looks at some of the subtle aspects of synchronisation devices – specifically oscillators used in small cell equipment, which may not be obvious in the primary selection and basic testing of the synchronisation elements. The linearisation aspect of voltage controlled TCXOs and special techniques in TCXO testing are discussed and their impact on synchronisation is investigated.

Synchronisation Requirements

3GPP defines the air interface synchronisation requirements for small cells. As small cells start to co-exist with macro cells, the interference mitigation requirements become important. CoMP and eICIC are techniques used to enhance the interoperation between the small cells and macro cells in a HetNet architecture and these require the need to have strict phase accuracies at the base stations.

Radio Technology	Base Station Description	Frequency Accuracy (FDD & TDD)	Phase Error (TDD)	CoMP and eICIC (FDD & TDD)
LTE	Wide area, >3km radius	50 ppb	±5 µs	±0.5 to ±5 µs
	Wide area, ≤3km radius	50 ppb	±1.5 µs	±0.5 to ±5 µs
	Local area	100 ppb	±1.5 µs	±0.5 to ±5 µs
	Home BS, >500m radius	250 ppb	±1.33 + T_{prop} µs [1]	±0.5 to ±5 µs
	Home BS, ≤500m radius	250 ppb	±1.5 µs	±0.5 to ±5 µs

[1] T_{prop} is the propagation delay between the home base station and the cell selected as the network listening synchronisation source.

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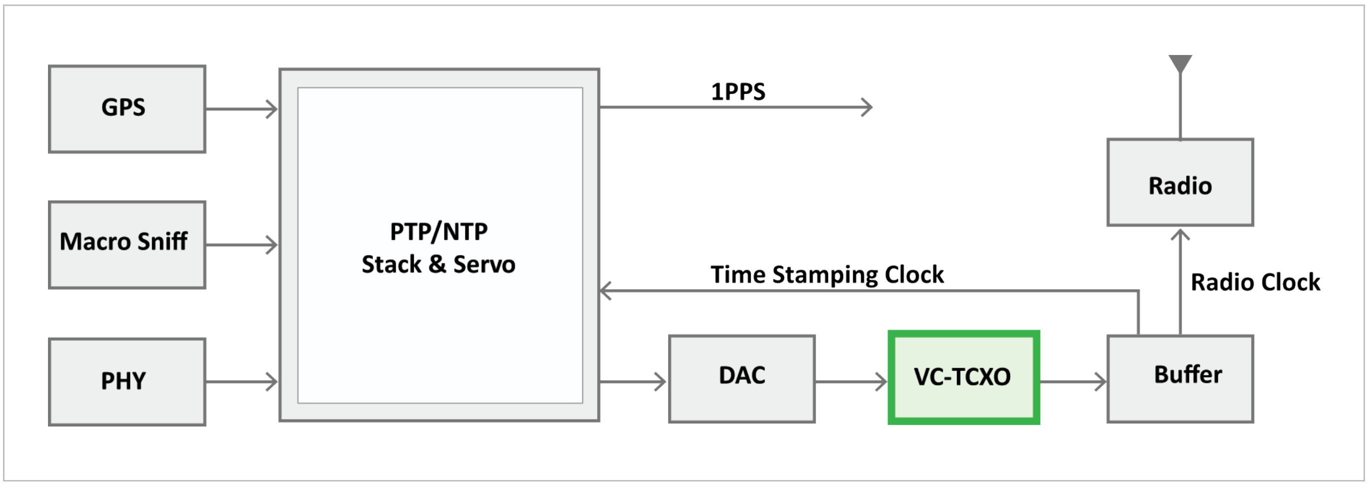
The transport network interface synchronisation requirements of small cells depends on the network interface used and the corresponding network requirements applied. For example, if the small cell device is part of a carrier Ethernet network supporting synchronisation, the small cell equipment may be compliant to the G.8262 Ethernet equipment clock specification; if the small cell terminates a PTP clock, then the equipment may be compliant to the G.8273.2 telecom slave clock requirements and so on.

Synchronisation Architecture

Small cells use multiple synchronisation sources to be resilient to failures. GNSS, macro sniff (network listening), NTP and PTP are technologies commonly used in the synchronisation of small cells.

The following diagram shows a commonly used timing flow architecture for small cells.



The synchronisation engine in the SoC drives the TCXO in the loop. This architecture is most common since the TCXO output can directly drive a radio interface with the required low phase noise for the air interface. It also delivers the low jitter requirements to drive the PHY interfaces and thus a single oscillator can be used for the radio interface as well as the network interface.

Linearity effect of the TCXO

A voltage controlled TCXO uses a varactor diode based implementation to change the output frequency. An internally generated compensation voltage combined with the externally applied control voltage is used to generate the output frequency of the oscillator. Such an implementation exhibits a non-linear frequency adjustment curve.

At the same time, a temperature compensation technique with defined accuracy is required to achieve a target level of temperature stability from a crystal resonator. Ideally, once compensated for the temperature impacts on the frequency, the device should provide performance within the specification. In general, the non-linearities in the frequency versus voltage characteristics of the device will result in the frequency versus temperature effects being dependent on the adjustment voltage of the TCXO.

For voltage controlled TCXOs, in order to change the output frequency of the device, the external control voltage is applied across the varactor. This application of the external voltage source changes the voltage across the varactor. The previously adjusted temperature versus frequency correction does not hold the frequency performance of the device against temperature and the device may go out of specification.

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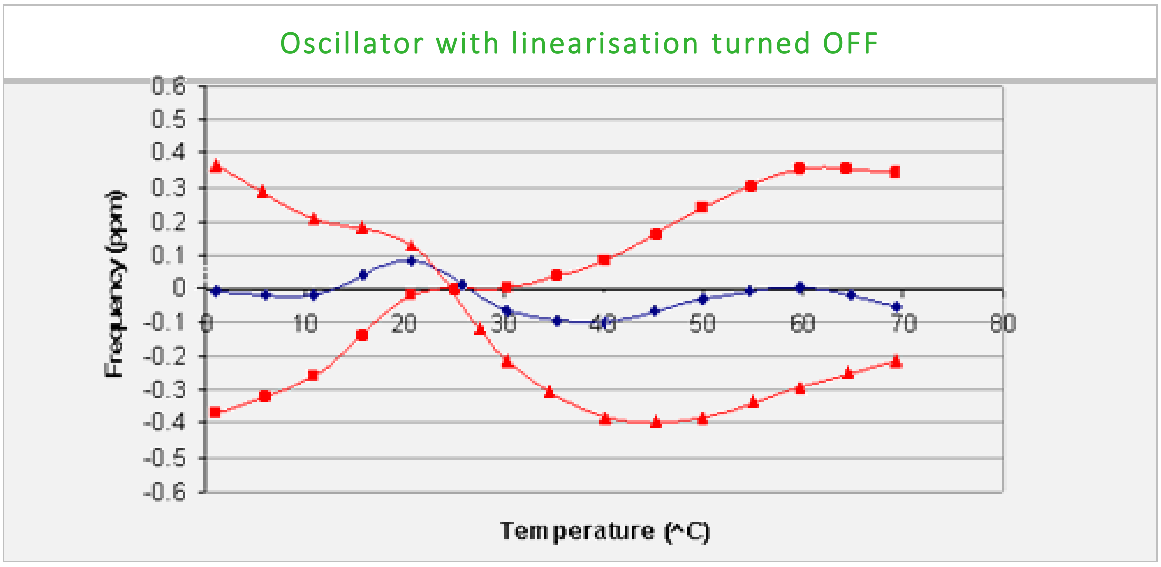
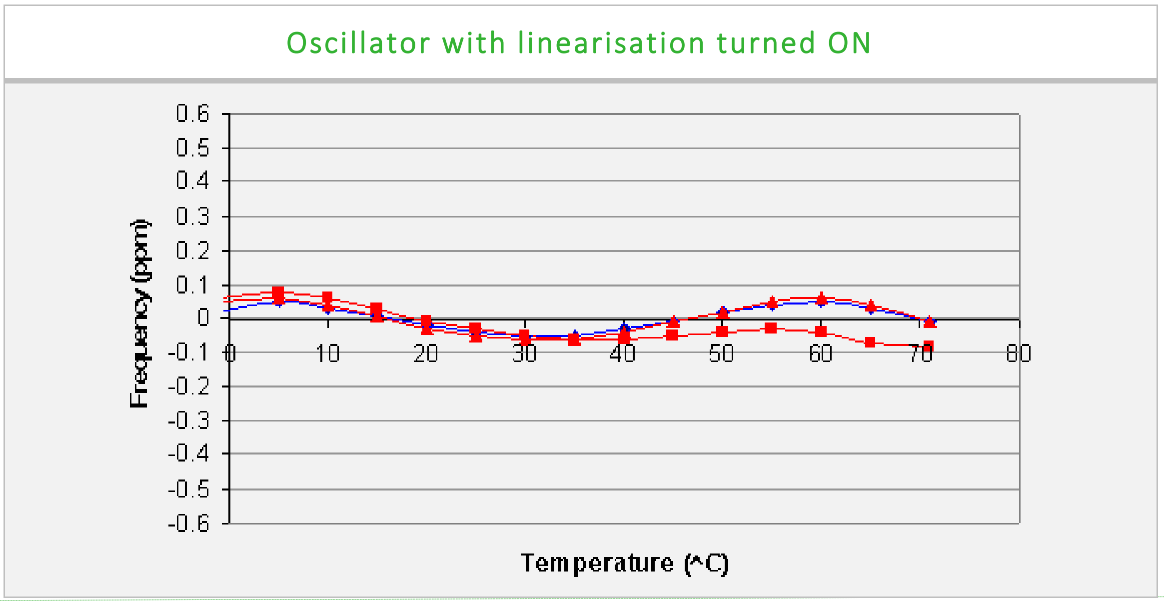
Rakon's Pluto+ based VC-TCXOs apply a patented compensation technique to stop this situation occurring. A linearisation block applies pre-distortion to signals so that frequency sensitivity as well as temperature performance at adjustment signal extremes, are maintained within specification.

To illustrate these effects, the following example is shown. On the graph, the blue line shows temperature versus frequency performance at nominal pulling voltage. The red lines are the temperature versus frequency performance at the extremes of pulling ranges when extreme adjustment signals are applied. It is clear from the graph that a TCXO specified at 0.1 ppm over temperature does not perform to the specification at the extremes of the pulling ranges.



With the patented compensation applied, or with the linearisation effect turned on, the following figure shows the performance of the device at a nominal frequency as well as at the extremes of the pulling ranges. It is clear from these graphs that the linearisation has a big impact on the temperature stability of the device across the entire pulling range and is now able to achieve a 100 ppm stability over temperature.



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Impact of Linearisation on Small Cell Designs

This effect has a significant impact on the implementation of small cells. Small cells integrated with TCXOs, in general, are trimmed close to nominal voltages, depending on the initial frequency accuracy of the oscillator. The temperature versus frequency curve performs well at nominal tuning voltages, for any TCXOs. As the equipment goes to the field, the TCXOs start to age and the output frequency starts to drift from its initial frequency. Since the TCXOs are in the frequency synchronisation loop, the loop pulls back the frequencies to nominal by altering the adjustment voltages at the voltage control input of the TCXO.

With non-linearised TCXOs, this effect of adjustment for ageing will create abnormality in the temperature versus frequency performance. The output frequencies may drift over the specified temperature range and may not be compliant any more as required by the standards of air interface requirements. Therefore, over a period of time, the equipment may not be able to synchronise properly to the network and may become unusable.

Rakon's TCXOs are fitted with a patented 3rd order compensation polynomial which will pre-distort the control signal to keep the linearity across control voltages and across the temperature range at the same time. As shown in the figure on page three, the oscillator performs within specifications at extremes of the pull ranges across the temperature range. This is a key differentiation of Rakon TCXOs compared with commonly available, general purpose TCXOs.

The adjustment sensitivity (tuning slope) has an impact on the holdover performance as well as the loop performance of the system. It is desired to have minimal adjustment sensitivity and sensitivity variation. The minimal adjustment sensitivity results in better resolution of loop control (in the digital world, the bit per ppb variation of frequency) and thus minimal initial holdover accuracy to ensure specific holdover performance over a specific period of time. A better granularity is achieved with a smaller adjustment sensitivity, which has defined set of digital bits to control a certain voltage range.

The reduced sensitivity variation can help performance of the loop. The loop may be designed with a target adjustment sensitivity. Big variation to adjustment sensitivity results in longer settling times and undesired output fluctuations.

Fine Resolution Temperature Testing to Avoid Activity Dips

Activity dips are sharp variations in crystal resonator behaviours because of the property of resonators. These could be as a result of poor crystal or blank design and manufacturing processes. Rakon employs fine resolution temperature testing to identify and screen out such oscillators that display activity dips.

Activity dips result in poor temperature performance, due to an overall frequency variation as well as a variation in the rate of frequency change. For example, the following figure illustrates an oscillator being tested with a target temperature sensitivity of 0.05 ppb/◦C using two different testing systems, one with 8 test points across the entire temperature range and the other with 112 test points.

It is seen that a huge frequency swing happens because of the activity dip between temperatures 50°C and 70°C that goes unnoticed on an 8 point temperature testing system. The first testing system will 'pass' the device under the test assuming that the maximum slope is only 0.02 ppm/◦C whereas the second testing system will be able to identify the 0.12 ppm/◦C slope during the activity dip and therefore 'reject' the device. Rakon has developed proprietary testing equipment which performs high resolution testing and is able to screen and eliminate oscillators that don't meet the higher performance requirements.

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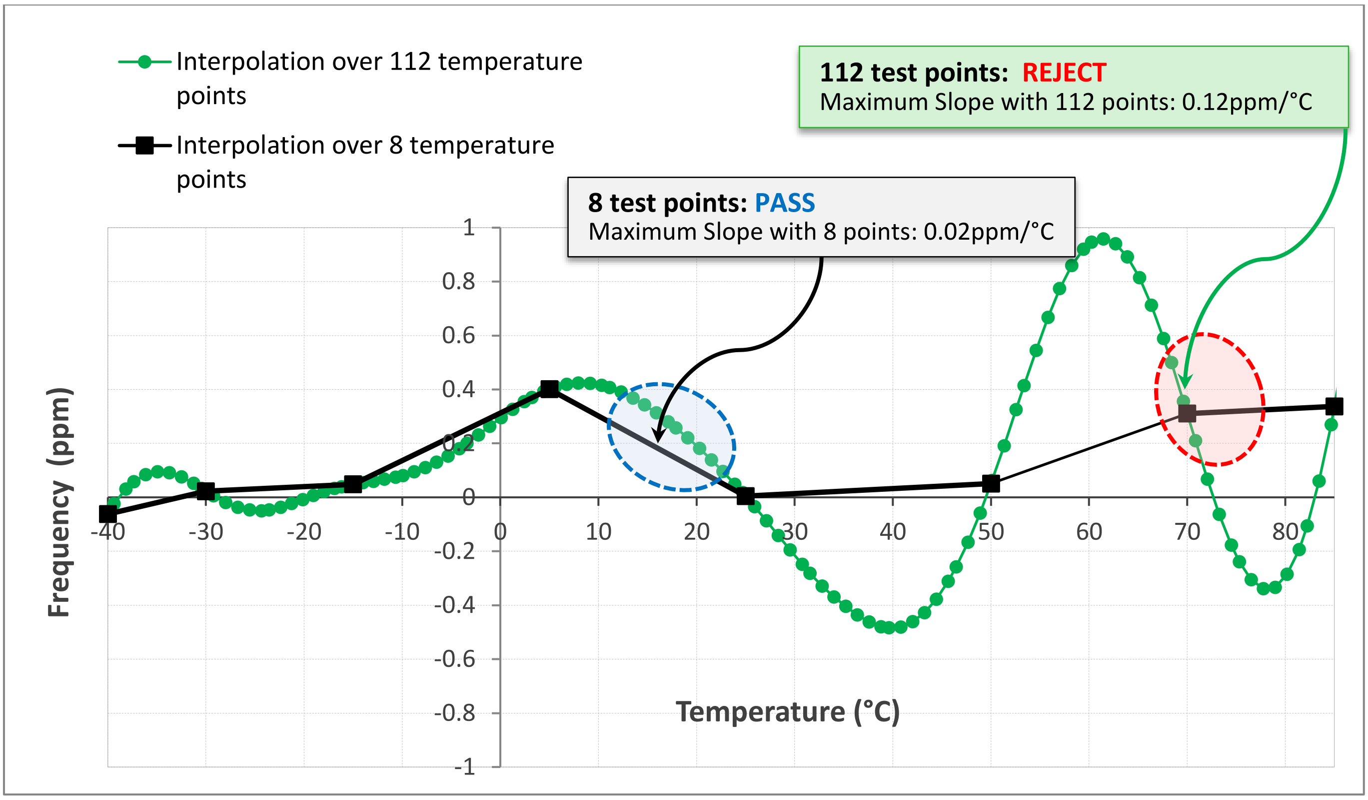

Small cell implementations commonly use NTP or PTP based synchronisation sources. These are packet based synchronisation technologies and are radically different from the traditional circuit switched physical layer synchronisation techniques. The events used to trigger the PLLs are very low frequent time stamps and may have undergone delay variations when passing through various network elements. Thus, in general, the loop filter bandwidths of the PLLs are much lower in packet based networks compared to traditional networks.

With such low bandwidths, stable oscillators are required on the loop designs as the oscillators present a high pass filter response to the output of a PLL based at the loop filter value of the PLL. Therefore, to achieve a certain level of output clock performance, stable oscillators are required as the filtering bandwidth becomes lower.

Therefore, oscillators that have defined temperature performance are required for such designs, both in terms of overall temperature stability as well as temperature slope performance. In general, commonly used temperature ramp rates are 0.5°C /min or 1°C/min. At these ramp rates, certain frequency variation performance is important to achieve certain performance levels.

Rakon designs, manufactures and maintains its own specific testing chambers for its oscillators. With a history of testing millions of customer grade TCXO devices per week, Rakon has the experience and expertise to mass produce such high end high quality devices in volume.

Summary

Rakon offers the industry's best performing TCXOs for small cells. Rakon TCXOs can achieve temperature stabilities as low as 50 ppb across temperature ranges (10ppb/day long term ageing at 15 ppb/°C temperature sensitivity) and with very low phase noise performance. They are uniquely designed incorporating patented technology which performs a linearisation technique to keep the oscillator operating within specification. Rakon TCXOs are tested using the highest quality test equipment available in the industry.

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This ensures the performance of the oscillator is sustained across the life of the equipment – a 'must have' for the mobile network operator.

References

1. K.R. Ward Rakon UK Ltd.; *"A NOVEL APPROACH TO IMPROVING THE STABILITY OF TCVCXO TEMPERATURE PERFORMANCE"*
2. Small Cell forum *"Synchronization for LTE Small Cells"*

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