Oscillators for Small Cells

– Key Technical Aspects

White Paper

Introduction

The proliferation of Smart Phones and Tablets has resulted in enormous growth in mobile broadband data traffic. As a result, carriers are improving their network infrastructure to accommodate the ever-increasing traffic. In this context a new generation of wireless access components and subsystems has been proposed which are called Small Cells.

With the introduction of Small Cells, the building blocks of wireless access systems are being re-drawn. This paper looks at the challenges of the synchronisation requirements, discusses oscillator requirements and suggests design considerations for the clocking aspects of Small Cells. This paper also presents advanced solutions to address synchronisation issues.

Small Cells – Best for Service Providers, Best for Consumers

Small Cells encompass sets of systems and components to ease the implementation of cellular mobile communication. In varying capacities, Small Cells enable mobile coverage for the home and enterprise and for urban and rural environments. Deployed along with the existing Macro Base Station network, Small Cells primarily offer capacity offload – diverting the heavy data users away from the Macro Base Station to the Small Cells. Small Cells also address coverage, being a cost effective way to reach to the farthest corners of the buildings and to the remotest rural areas, thus improving the overall efficiency of the network. Small Cells also offer numerous other advantages for the service provider such as increased customer 'stickiness', self-organising capability, and fixed mobile convergence.

For consumers, it offers coverage and capacity. It gives enormous opportunities for location-based services, unified billing and other applications.

However there are technical challenges for Small Cell implementation such as interference mitigation (with Macros as well as other Small Cells), Backhaul Networking, Synchronisation etc. Bodies such as the Small Cell Forum are working to resolve such issues. Small Cells offer an excellent technology option to roll out improved mobile networks.

Clocking and Synchronisation Requirements in Small Cells

In general, base stations require two sets of synchronisation aspects: network requirements and air interface requirements. Overall, GSM[1] and WCDMA[2] and LTE-FDD[3] networks only need frequency accuracy of 50ppb to 250ppb at the air interface for synchronisation to meet the Doppler shift effect of moving User Equipment (such as Handsets). With 4G/LTE-A[4] and 4G/LTE-TDD[5] systems, there is an additional phase accuracy requirement of ±1.5µs between adjacent base stations for various reasons such as handover and interface mitigation. 4G/LTE-A features additional positioning accuracy requirements that suggest a <±0.5µs phase error requirement.

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[1] **GSM:** Global System for Mobile.
[2] **WCDMA:** Wideband Code Division Multiple Access.
[3] **LTE-FDD:** Long Term Evolution – Frequency Division Duplex.
[4] **LTE-A:** Long Term Evolution – Advanced.
[5] **LTE-TDD:** Long Term Evolution – Time Division Duplex.

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Traditionally, base stations were backhauled through circuit switched networks which carried synchronisation from the network. The traditional methods coupled with GNSS[6] systems enabled base stations to meet the synchronisation requirements easily. High end equipment like Macro Base Stations could afford to have multiple expensive high stability oscillators which kept synchronisation intact and could work for days without synchronisation signals from the network.

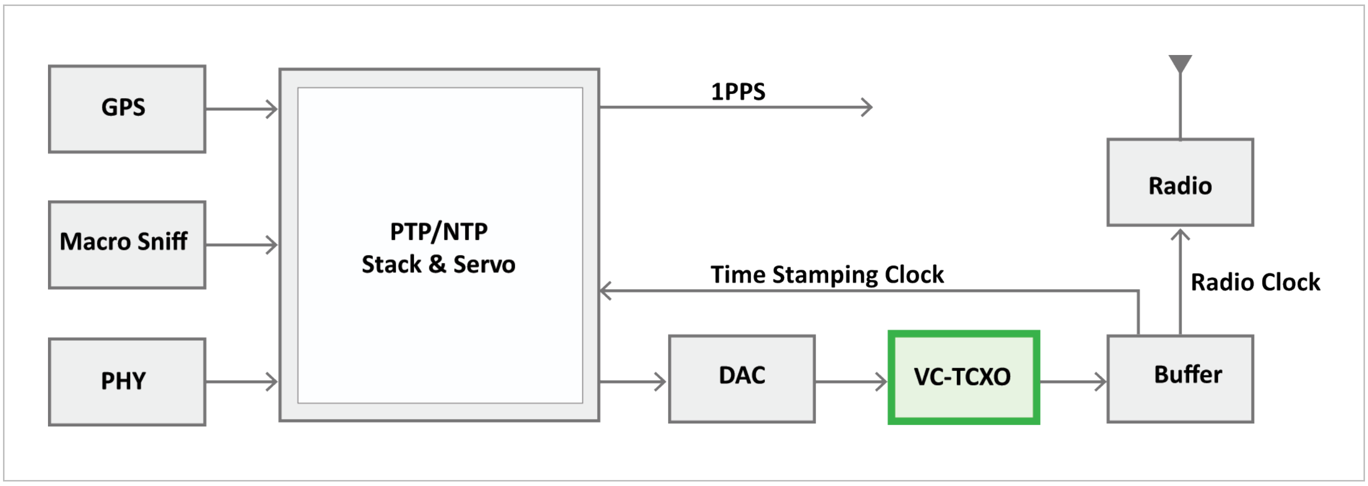
With the introduction of packet based backhaul techniques, synchronisation has become a challenging topic. With the low cost structure of the Small Cells, Synchronisation methods are being re-examined. GNSS, Cellular Network listening (Macro Sniff), Synchronous Ethernet, other physical level recovered clocks (such as Cable and DSL[7]), as well as packet base synchronisation techniques (such as PTP[8] and NTP[9]) are the most popular methods of synchronising Small Cells. In many cases, hybrid technology options (GNSS, PTP and SyncE[10]) are considered to keep the quality of the recovered clocks as high as possible. This white paper primarily assumes packet based synchronisation methods in the requirements and considerations outlined.

The RF interfaces, along with accurate frequency and phase information, also require low phase noise in order to maintain efficient RF performance. Traditionally multiple oscillators were included in the system to perform various functions. With the new cost models, new architectures are envisioned to use a single oscillator to take care of the synchronisation requirements, as well as RF interface clocking.

With Small Cells moving towards the integration of various functions such as broadband interfaces as well as gateway functions, the usage of high-speed high quality unrelated clocks are required. There are requirements targeted for simple, cost effective devices that provide multiple unrelated outputs at lowest power consumption, minimal external components and the smallest footprints.

Synchronisation Aspects of Small Cells

The following figure illustrates the current Small Cells clocking architecture.



[6] GNSS: Global Navigation Satellite System.
[7] DSL: Digital Subscriber Line.
[8] PTP: Precision Time Protocol.
[9] NTP: Network Time Protocol.
[10] SyncE: Synchronous Ethernet.

Macro Base Stations require 16ppb accuracy from the legacy systems. Traditionally synchronisation in such systems was driven either from GPS[11] or from the circuit switching T1 or E1[12]networks, which backhauled the traffic. Stratum 2 level oscillators were used for holdover when other timing sources failed. Combining all of the above, resulted in satisfying the network interface timing requirement.

Small Cell standards do not have a clear definition of backhaul timing requirements at present but the Standard bodies are reviewing the requirements. However, if the transport interface is part of the Small Cell equipment, the required standards conformances are in place. If the Small Cell uses synchronisation through an Ethernet PHY, then SyncE compliance needs to be satisfied.

At the air interface, there are requirements for frequency accuracy as well as phase alignment. Frequency accuracy is required to handle the Doppler shift effect of moving handsets. In the FDD systems, the uplink and downlink transmissions happen on different frequency bands and the downlink uses a modulation technique called Orthogonal Frequency Division Multiple Access (OFDMA), which requires orthoganality between subcarriers. With Doppler issues, at a defined maximum speed of the user equipment and defined maximum instability of oscillators used, the interference between subcarriers can only be avoided with defined frequency accuracy at the air interface. Frequency synchronisation is also required for the smooth handover of the User Equipment from one cell to another without call dropping. All this assumes that the User Equipment is able to synchronise to the Small Cell in the first place with the Small Cell having the right frequency error limit according to the specifications.

With the interface mitigation techniques required in 4G/LTE-A, the phase alignment requirement is in place even for FDD systems. In HetNet scenarios, the signalling channel needs to be synchronised between the Macro Cells and Small Cell, thus requiring phase alignment.

In 4G/LTE TDD systems the same channel is used for transmit and receive and there is a need for phase alignment to allow both duplexing of this channel and in order to synchronise the cells and the User Equipment. The issues of interference mitigation techniques are still applicable to the 4G/LTE TDD systems as well. The CoMP, eICIC requirements are currently being defined by 3GPP.

Oscillator Requirements for Synchronisation

When GPS or GNSS timing techniques are used, the PLL loop can be wide compared to network PLL standards, a loop bandwidth of 10Hz or higher is possible. Commercial GPS modules offer phase alignment accuracies of tens of nanoseconds (ns) with a TCXO (100 – 500ppb) as a source timing reference. Similar results should be possible with Network Listening (Macro Sniff) techniques. Packet based timing technologies are a bit more uncertain, and performance depends on a number of factors.

Small Cell backhaul may or may not be capable of implementing the transport network architectures suggested by the ITU synchronisation study groups. Thus the right engineering of the backhaul and grandmaster positioning is required to effectively support the phase accuracy requirements. With packets synchronisation techniques, depending on the type of network and traffic patterns, narrower bandwidths are used in the timing servos. For example, the suggested bandwidths for G.8263 clocks for frequency only specifications are 1mHz or lower, with no on path support offered by the other elements of the network. With all elements in the network and supporting packet timing the G.8273.2 Telecom Time Slave Clock specifications suggest 0.05 – 0.1Hz loop filters. It is recommended to use OCXOs (10 – 50ppb) for such implementations.

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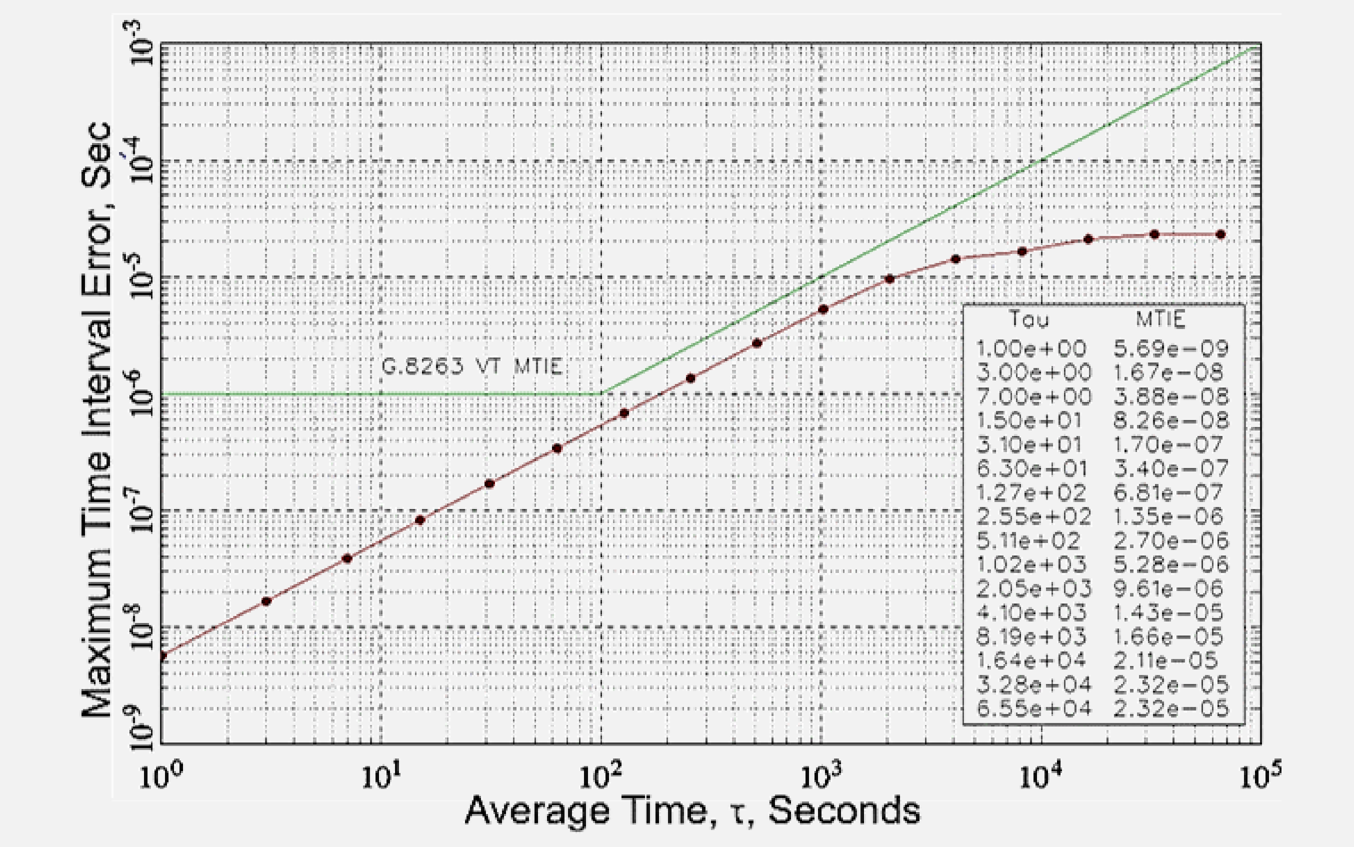
[11] **GPS:** Global Positioning System.

[12] **T1, E1: T1 and E1:** T1 is a digital carrier signal that transmits the DS – 1 signal. It has a data rate of about 1.544 megabits / second. It contains twenty four digital channels and hence requires a device that has digital connection. E1 is similar to the T1. T1 is the North American term whereas the E1 is the European term for the transmission (digital). The data rate of E1 is about 2 megabits per second. It has 32 channels at the speed of 64 Kbps.

With packet based synchronisation, the medium term stability requirements of the oscillators are key. Traditionally, the transport equipment used to have Stratum 3 level stability requirement to support 0.1Hz to 10Hz loop bandwidths in the systems. Packet based clocks have much lower bandwidths and to meet the wander generation metrics across the operating temperature range, more stable oscillators are required. Rakon works with vendors of packet based algorithms to test the oscillators for various loop bandwidths and tune them to be able to meet the standards requirements. The following shows MTIE testing done at 1mHz with a Rakon oscillator meeting the standards masks.

1mHz Loop Filter, 10°C/hour – Mercury™ IC OCXO RFPO45 G.8263



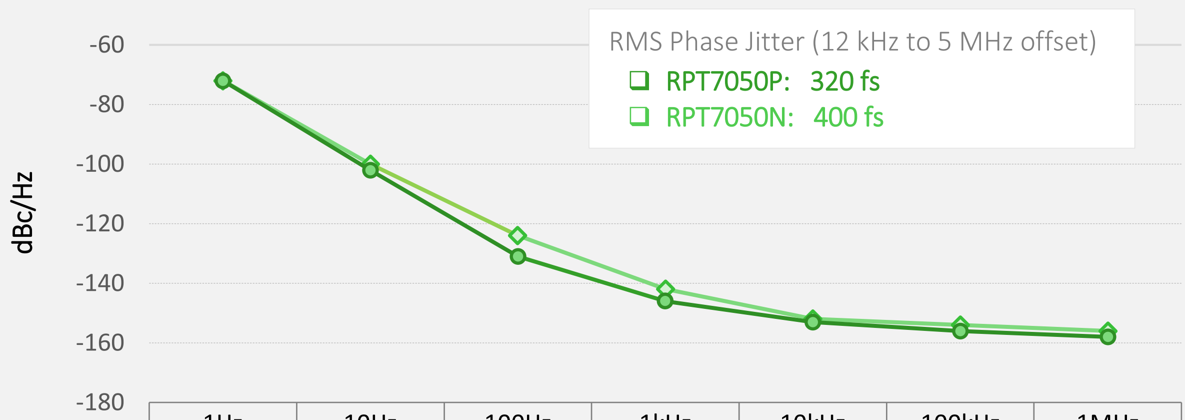
Oscillator Requirements for Better Phase Noise

Another aspect of clocks in Small Cells is the requirement for low phase noise at the radio sections. As previously mentioned, the 4G/LTE air interfaces uses OFDMA methods and QAM techniques. To efficiently use the available bandwidth, it is required to pack as many bits/s/Hz in the available spectrum as possible. As the processing power of the base band processors increase, the number of symbols that can be processed in real time increases, pushing up the bit per second per hertz. 3G technologies use 16 QAM, 4G/LTE defines 64 QAM and 4G/LTE-A allows up to 256 QAM. This means that there are more constellations to be decoded and thus they need to be as error free as possible. The measure of deviation of actual constellation from ideal location is called Error Vector Magnitude. One of the key contributors of large EVM is the low phase noise of the reference clock used to create the constellations. As the phase noise of the clocks that drive the radios is reduced, the EVMs are reduced, thus improving the transmitted and decoded signal quality.

Traditionally, in Macro Base stations, the Base Band Unit processes a master clock combining all possible synchronisation sources. Then the clock is sent to the Remote Radio Heads through the CPRI interface through fibre links. Once the clock is processed through silicon VCOs, in general, it has a high close-in phase noise, which is not good enough to drive radio clocks. The Remote Radio Units (RRU) process the clocks through VCXOs and multiplies them to the rates required for the transceivers.

Rakon works with Base Band SoC solution vendors and radio solution vendors to make sure that the phase noise requirements for best performance of the solution are met with ease. Following is a typical phase noise plot from Rakon's RPT series of TCXO featuring patented Pluto+™ compensation technology.

20MHz Phase Noise Comparison – Pluto+™ TCXO RPT7050P/RPT7050N



	1Hz	10Hz	100Hz	1kHz	10kHz	100kHz	1MHz
RPT7050N	-72	-100	-124	-142	-152	-154	-156
RPT7050P	-72	-102	-131	-146	-153	-156	-158

Oscillator Requirements for Network Interfaces

The network interfaces, typically SyncE, need to meet ITU requirements. One of the key aspects to meet, is the jitter requirement on the line interface. The jitter on the band of 12kHz – 20MHz is of importance. To have a lower jitter on the line, it is essential to have a lower jitter value on the source oscillator. In contrast to the close in phase noise, which was required at the radio interface, the network interface needs to have very low mid-band and noise floor performance on the oscillator.

Small Cells implement more cost sensitive implementations and mostly use a single, stable oscillator in the system, for both the air interface as well as for the network interface.

Linearity Aspects of the Clocks

There are many ways of implementing a timing recovery loop in a system, the most common approach in Small Cells is where the servo engine that processes synchronisation drives a VC-TCXO or VC-OCXO to generate the clock for the system, as described in the general timing flow model. The generated clock drives back the loop to complete the closing loop of the system. For example, in a NTP/PTP based implementation, this generated clock goes back into the time stamping engine which in turn generates local time stamps which feeds the clock recovery algorithm.

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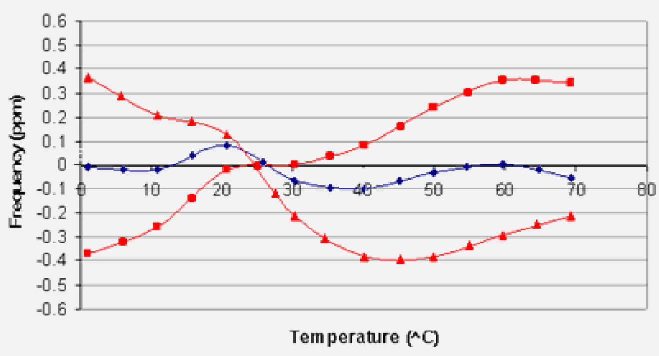
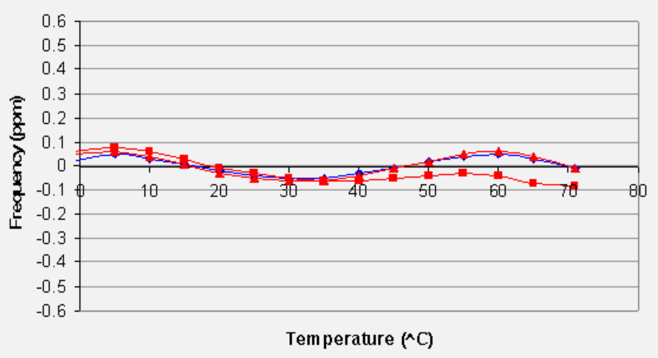
The servo algorithm drives a DAC[13] or a PWM[14] system and the filtered signal drives the Voltage Controlled Oscillator (VCO). The servo algorithm expects a certain level of linearity between the control words generated and the frequency change that happens at the oscillator output at all ranges and at all temperatures. The linearity helps the loop to converge faster and with minimal perturbations, depending on the type of control loop implemented.

Another key aspect is the behaviour of crystal-based oscillators, such as the frequency changes over time or 'ageing'. Ageing results from changes in the crystal structure and the internal environment over time which in turn alters the resonant frequency. Nominally at the middle of pulling voltages, the frequency versus temperature effect may have linearity within the required temperature ranges. But over time, when ageing happens, it is required to pull back the oscillator to nominal frequency, but at the extremes of pulling voltages the frequency versus temperature effect can be degraded due to the non-linearity of the voltage control which is typical in standard VC-TCXOs.

Rakon's patented Pluto+™ technology has implemented a polynomial compensation on the "linearisation" technique and thus the oscillator performance is superior to generic oscillators available.

Oscillator with linearisation turned OFF	Oscillator with linearisation turned ON
	

Holdover

Holdover is the ability of the system to maintain the synchronisation within acceptable limits when the source of synchronisation is lost. Depending on the requirements of the system, the system may need frequency holdover or time holdover. The duration of holdover is the capability of the system based on the implementation details, for example, an OCXO will be able to hold time within acceptable limits for a longer time period compared to a TCXO and so on.

From an application perspective, the holdover is required to mask the synchronisation failure of a system. The failure of the system could be due to all synchronisation sources failing forever or for a short period of time. For example, for a GNSS only synchronisation situation, there could be a scenario where the GNSS fails due to an antenna failure or GNSS system failure. The service provider needs to correct the fault within a targeted turnaround time which determines the holdover time. In another scenario, it could be a GNSS jammer, which could be upsetting the synchronisation for a short period of time, perhaps less than one hour. It could also be an enterprise Small Cell scenario where the system administrator could reach and reset the system to recover synchronisation. The holdover

[13] **DAC:** Digital-to-Analog Converter.
[14] **PWM:** Pulse- Width-Modulation.

requirement of a system is determined by the service provider on how the system needs to be serviced in the event of a synchronisation failure.

The frequency accuracy requirements of 4G/LTE systems can be maintained confidently for weeks or even months with disciplining algorithms and a properly designed oscillators. Once the servo accuracy is determined and the operating ambient temperature variation of the system is studied (e.g. indoor installation with restricted temperature operation variation versus outdoor ambient temperature operation) the stability of the oscillator over the temperature range and the ageing parameters can be considered for the selection of the oscillator.

For illustration, if the turnaround time on a service call is assumed to be couple of days, for a service that requires ±250ppb of accuracy while operating at 0 to 80°C, assuming that servo accuracy is ±30ppb, an oscillator with stability performance at ±80ppb at 0 to 80°C and an ageing performance of ±20ppb gives sufficient margin for operation even for a week without re-synchronisation.

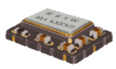
Phase error is the accumulation of frequency offset. The phase accuracy requirements of 4G/LTE air interfaces are much more challenging to meet for long term holdover requirements. The temperature change range, the rate of change of temperature change and the operating temperature range can determine the frequency variation and in turn the phase variation.

Traditionally the synchronisation testing is done over the operating temperature range, following the procedures recommended in the temperature endurance and cycle testing standards. However, in a realistic scenario, it is not feasible to see a temperature change from each extreme, i.e. -40 to +85°C within 24 hours. New synchronisation testing profiles such as the one below are being discussed at various forums. Constraining the synchronisation testing to such finer testing windows allows the use of cost effective oscillator solutions within systems.

Parameter	Stable Temp (Indoor)	Variable Temp (Indoor)	Stable Temp (Outdoor)	Variable Temp (Outdoor)
Example Operating Temperature Range	10 to 70˚C	10 to 70˚C	-40 to 85˚C	-40 to 85˚C
Sync Testing Temperature change range	±1˚C	±5˚C	±3˚C	±20˚C

For example, an indoor Small Cell inside an enterprise, which is inside a well air-conditioned server room may only see a temperature variation of ±1˚C. An air-conditioned mall with its open doors and air curtains may have a variation of ±5˚C. The service provider profiles the use case scenarios to define the synchronisation performance for each system requirement.

Rakon provides a wide range of solutions for Small Cells. The primary criteria for selecting the right oscillator is a combination of the synchronisation performance required by the radio interface in place, along with the synchronisation technology used and the holdover required. The following table summarises the solutions offered by Rakon.

OSCILLATOR SERIES ...	US-TCXO Pluto+™ RPT... 	IC-OCXO Mercury™ RMO ... 	Discrete OCXO ROX1490S4 ... 	Discrete OCXO ROX2522S4 ... 
Package Size	5.0 x 3.2 mm 7.0 x 5.0 mm	9.7 x 7.5 mm 14.4 x 9.5 mm	14 x 9 mm	25.4 x 22.0 mm
F vs T	50 ppb	10 ppb	10 ppb	5 ppb
Ageing	20 ppb/day	1 ppb/day	1 ppb/day	0.5 ppb/day
Slope	15 ppb/°C	1 ppb/°C	0.2 ppb/°C	0.1 ppb/°C
Frequency Holdover (100ppb)	1 week	>1 month	>3 months	>6 months
Time Holdover (±1.5µs @ 20°C window, 1°C/hr variation)	–	0.5 hour	3 hours	4 hours
Power	20 mW	350 mW	550 mW	1.5 W
Timing Applications Supported	NTP, SyncE	PTP, SyncE	PTP, SyncE	PTP, SyncE
Radio Interfaces	FDD	LTE TDD, LTE-A	LTE TDD, LTE-A	LTE TDD, LTE-A
Price	$	$$	$$$	$$$$

Conclusion – Rakon's Oscillator Solutions for Small Cells

Rakon offers the broadest range of oscillators optimised for the Small Cell market. As an early member of the Small Cell Forum, Rakon has been an integral part of the Small Cell Ecosystem enabling the synchronisation technology for Small Cells. With a wide range of TCXOs and OCXOs, Rakon is able to provide synchronisation solutions for a wide range of customer requirements.

Rakon has been working with many of the SoC vendors of Small Cells as well as RF Transceiver vendors and synchronisation solution providers to understand their requirements and develop and manufacture optimised products. From Rakon's extensive and automated manufacturing and testing facilities, Rakon supplies high performing solutions for Small Cell customers.

Rakon continues to invest in the future including the pending release of Rakon's innovative multi-output OmniClock™. The OmniClock™ product family has been developed to address the cost, performance and stability requirements of the next generation of Small Cells.

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