Oscillator Technology in Focus

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Contents

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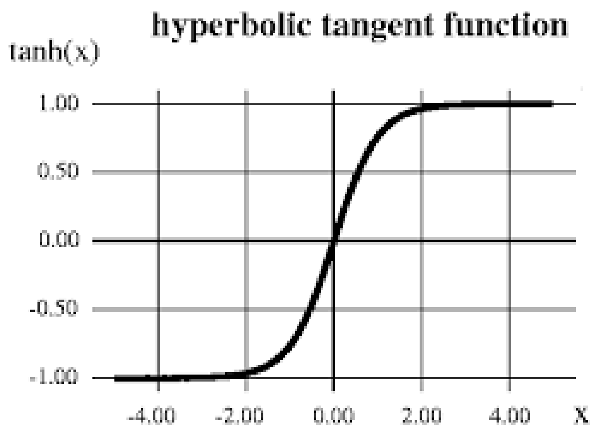
- Focus on the local oscillator requirements and advances for the radio head or remote radio unit(RRU)
- Discuss
  - Advances in high stability TCXOs
  - The evolution of mini OCXOs
- A short synopsis of Silicon and Quartz technology
- Consider the particular requirements of phase tolerance in the RRU and how this can be addressed

RRU Frequency, Time and Phase

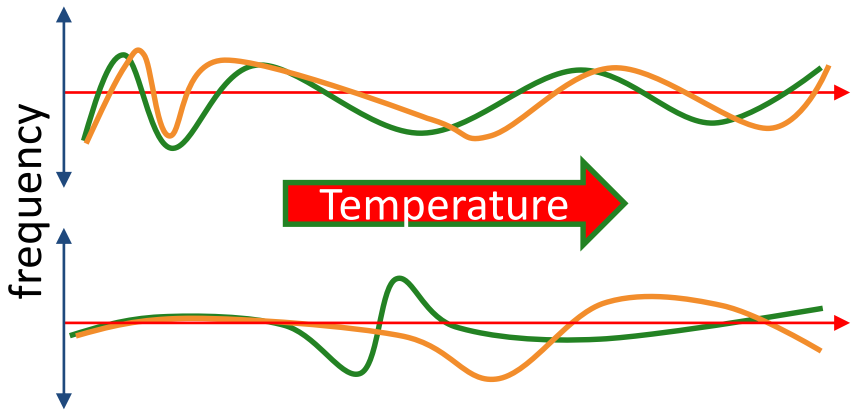
- **Drivers for Frequency stability**
  - Radio head air interface tolerance (50ppb → measured in 1ms)
  - If holdover is required, then dominated by the requirements for time synchronisation
    - To hold time to the sub micro second region over periods of many seconds
      - 1us over 100 seconds >> frequency accuracy of <10ppb
- **Drivers for Time stability (65ns/130ns/260ns in front-haul)**
  - At start-up, needs to be conditioned, has to have access to time reference
  - Conditioning bandwidth dependent on PTP signal quality and availability of physical layer synchronisation
  - Low loop bandwidth implies short-to-medium term environmental stability of oscillator
    - Determines the local oscillator frequency stability, lower slope (frequency change with time)
- **Drivers for Phase stability (sub-picosecond)**
  - Complex modulation schemes and higher carrier frequencies
  - Directional antenna, beam forming

Higher Stability TCXOs



Traditional High stability TCXO

- What are the challenges?
- How are they addressed in a “post-compensated TCXO”?
  - Take a high stability standard VC-TCXO and add extra isolation
  - Add extra compensation (either Digital or Analogue) to reduce:
    - Higher order residual error generated by original non-ideal compensation scheme
      - Largely predictable, 6th order comp. implies 7th order error.
      - Piecewise Linear combination
    - Perturbations in frequency temperature curve of crystal
      - Unpredictable and more variable
      - Multiple Tanh(x) segments, give flexibility
  - Digital compensation requires high resolution digital temperature sensor and high resolution D/A, to reduce digitation effects.



The challenges, Standard TCXO device construction

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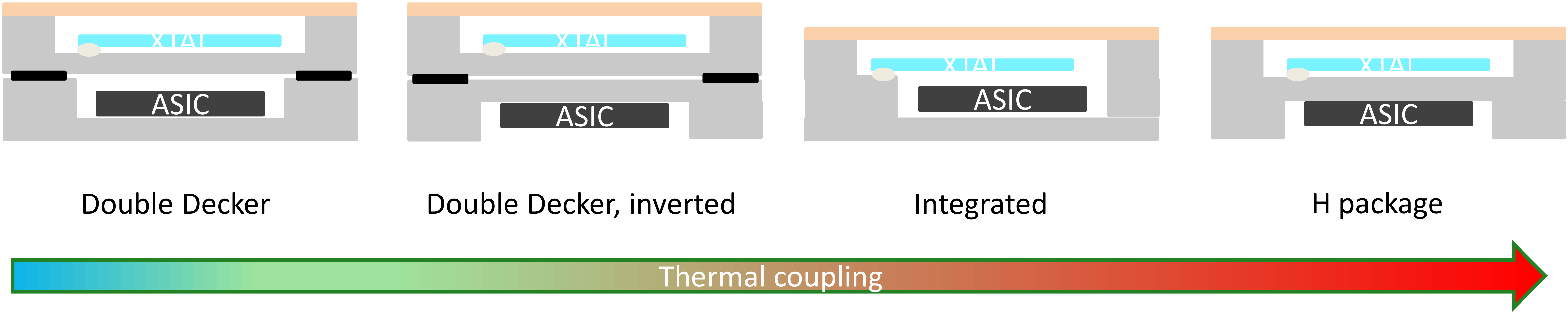
Traditional construction:

- Driven by cost and size requirements rather than performance (mobile devices, phones, location)
  - This has led to: 1 Resonator, 1 ASIC (including a built in temperature sensor) and 1 or 2 Ceramic Packages
- NB resonator and temperature sensor do not have strong thermal coupling


7x5

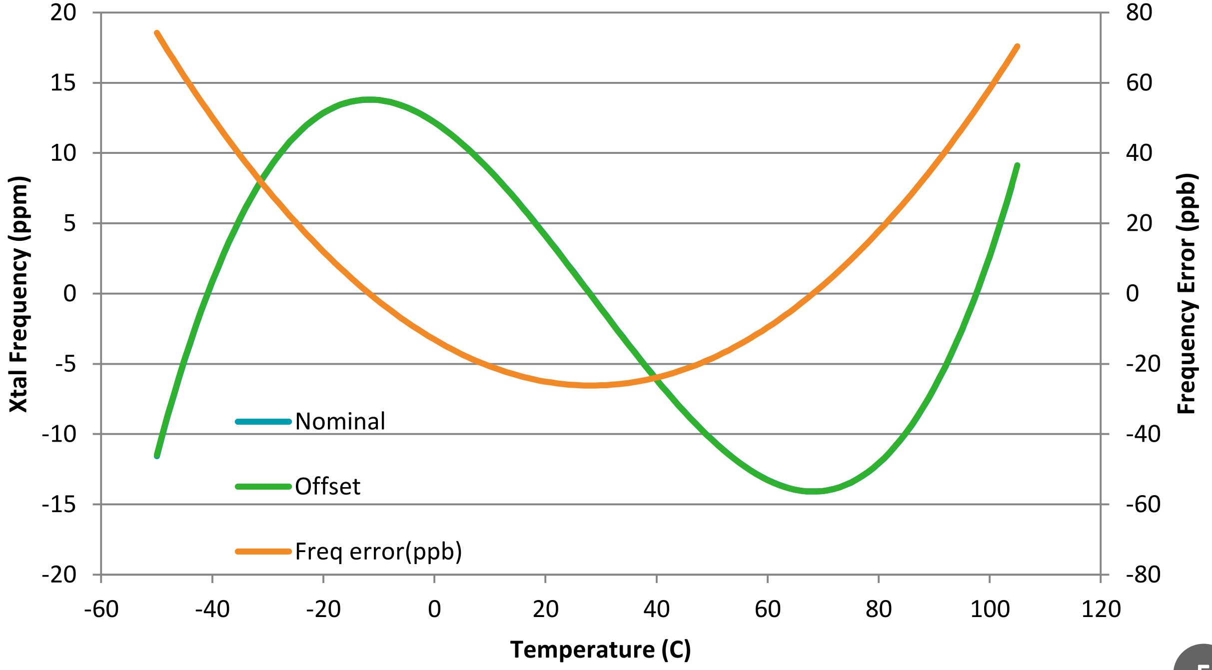
5x3.2

Post compensation TCXO devices - Isolation

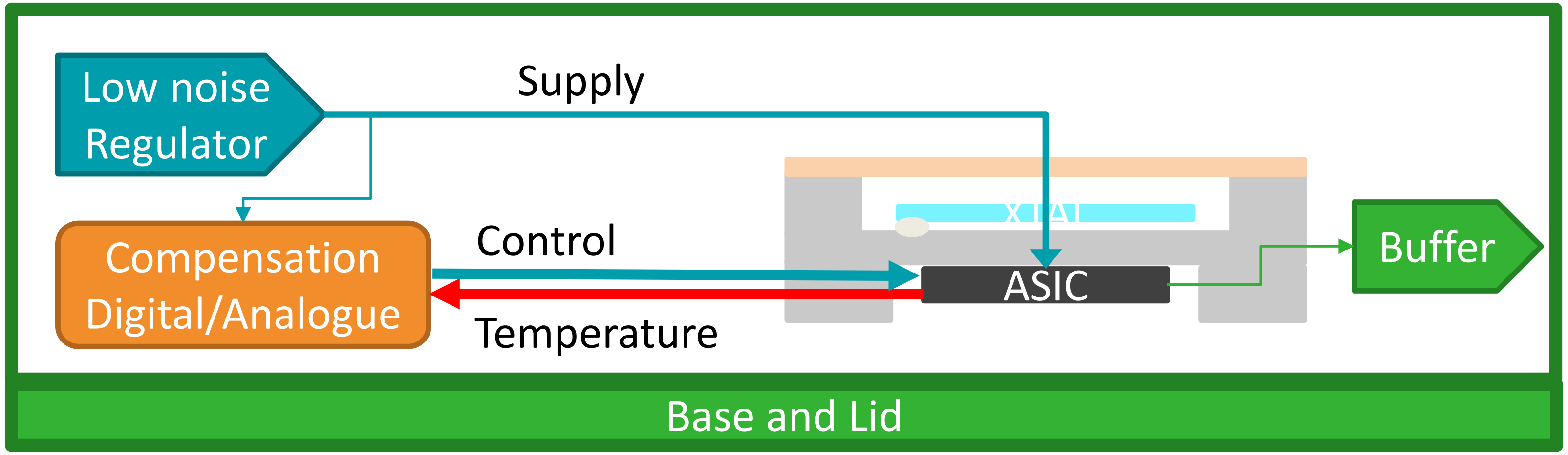
- **Isolation - thermal**
  - Supply and load variations: cause the power dissipation in the ASIC to change and hence induce a small temperature offset in the sensor relative to the resonator, distorting the frequency vs temperature.
  - Mounting: during calibration TCXO held in a jig, whereas in use it is soldered down on a pcb.
- **Isolation - electrical**
  - Single package - difficult to shield output stage from oscillator connections
- **Both these contributions to instability increase markedly with frequency**
  - Higher power consumption, hence larger power variation
  - Higher frequency, hence more feedback
- **Thermal degradation effect – Sensor to resonator differential**
  - Assuming say 10% supply on 6mA at 3.3V(20mW), ~2mW and thermal resistance of 25C/W then implies 0.05C variation. Gives ~ 50ppb degradation.

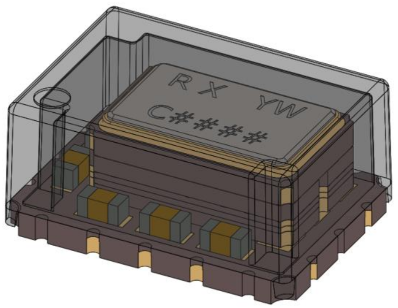
AT-cut crystal, effect of 0.05C temperature offset



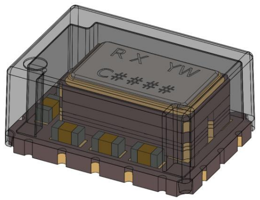
Post compensation TCXO

- **Elements:**
  - VC-TCXO
  - Temperature Sensor
  - Compensation
  - Regulator
  - Buffer
  - Lid & Base
- **Available sizes, Discrete construction**
  - 14x9, 9x7
- **With Integration**
  - Regulator, buffer and compensation together
  - 7x5 using 5x3.2 VCTCXO
  - 5x3.2 using 3.2x2.5 VCTCXO



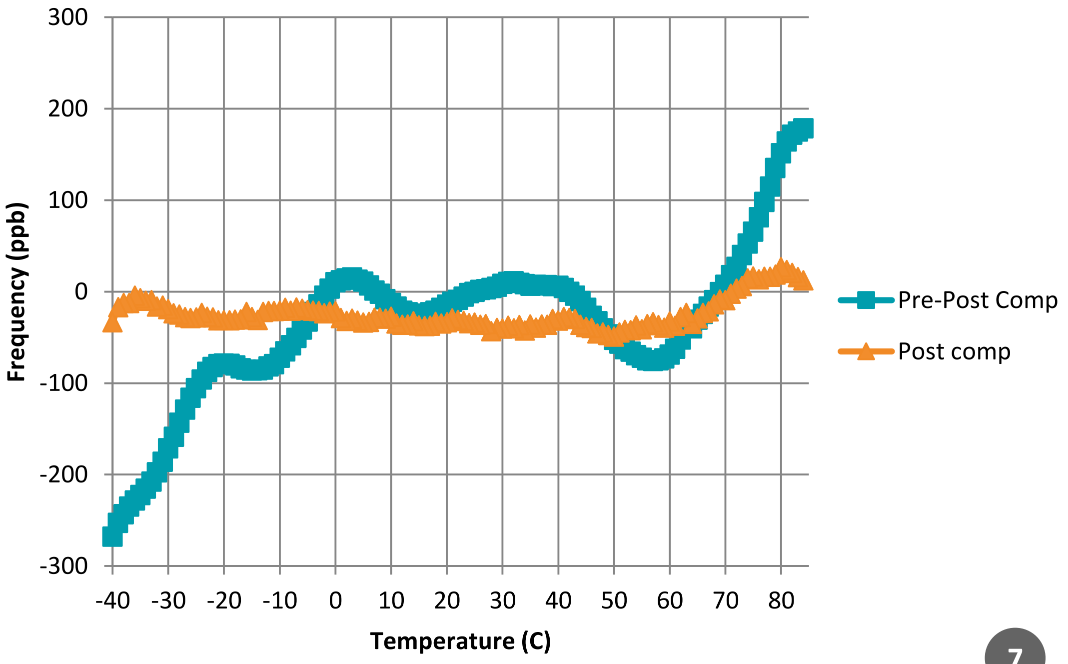


Higher stability TCXO



- **Post compensation and isolation enables**
  - Higher stability, (150ppb → < 30ppb)
    - Allows for wider temperature range -40 to 95 or 105C
  - Lower frequency vs temperature slope, (20ppb/C → < 5ppb/C)
    - Allows better sync tolerance, lower MTIE over longer loop times
  - Very low frequency change vs supply and load
    - 1 to 2 ppb, for 5% supply and 5pF load change
  - High PSRR, no requirement for low noise supply
  - Better airflow tolerance, reflow/mounting tolerance
- **Higher frequency oscillators with good stability**
  - Lower jitter whilst maintaining stability

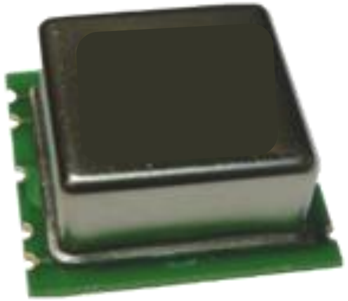
Post compensation example



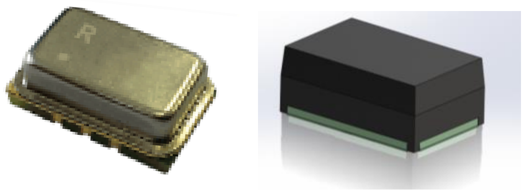
Mini OCXO - Evolution

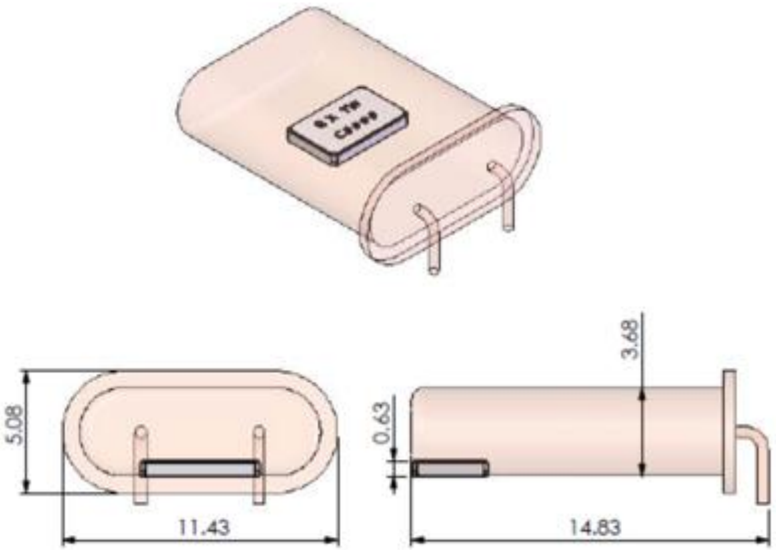
- **Crystals - mini OCXOs use strip crystals rather than traditional round blanks**
  - AT-cut strip (2010) → SC-cut strip(2016)
- **SC-cut strip, evolution**
  - 5x3.2 strip crystal → 3.2x2.5 strip crystal
    - Higher frequency, smaller package
  - Fundamental → Third overtone
    - Higher frequency, lower aging
- **Maturity and volume**
  - Process improvements
    - Lower aging
    - Higher yield
  - Design improvements
    - Lower g-sensitivity
    - Higher maximum temperature
      - 85 → 95C → 105C
  - Lower cost
- **New ASIC generations**

25x22x12

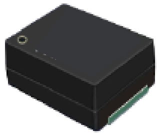


14x9x6

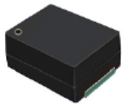




9x7x4



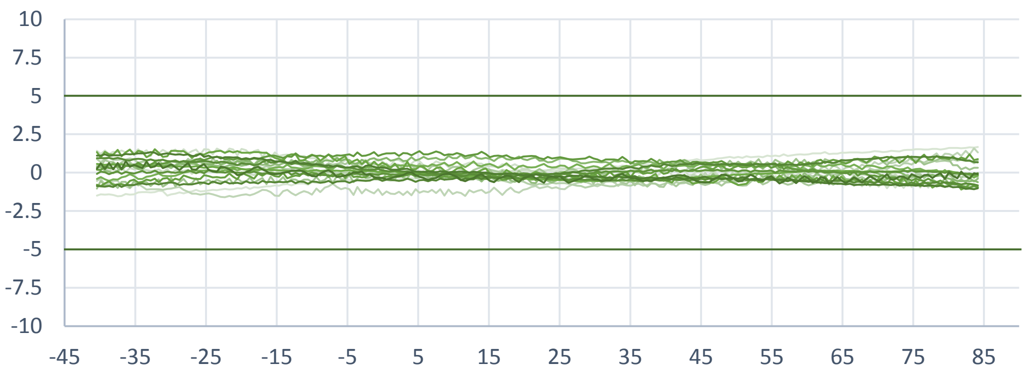
7x5x3



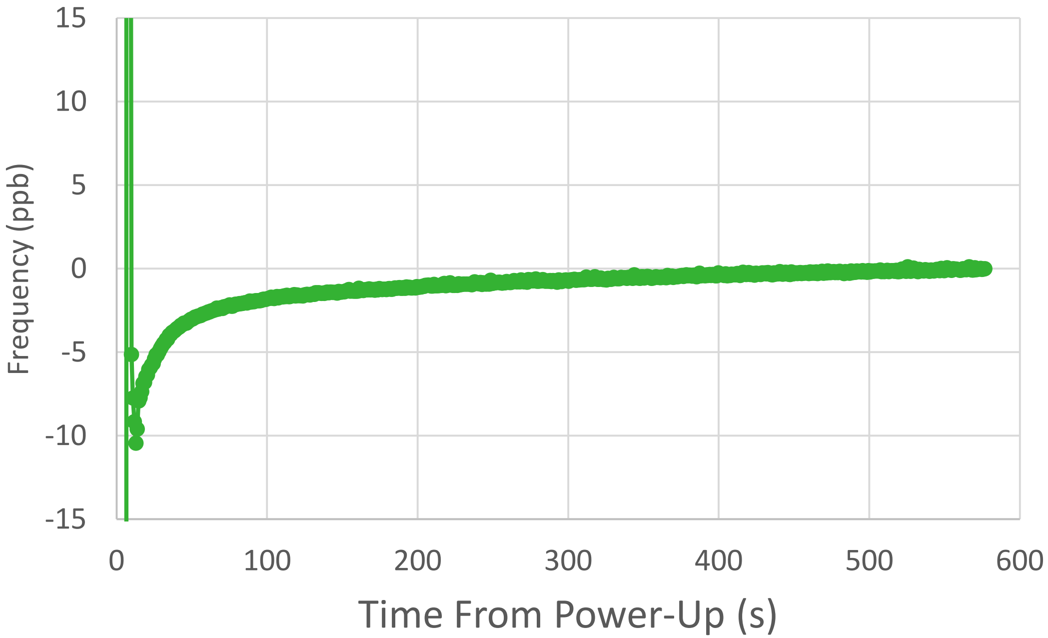
Fast start-up, with maintained stability

- Radio head traditionally had fast start-up VCXO
- Mini integrated OCXO (7x5)
  - Within 10ppb in ~10 seconds @ -40C
  - Compared to 2 to 3 minutes for 25x22 OCXO

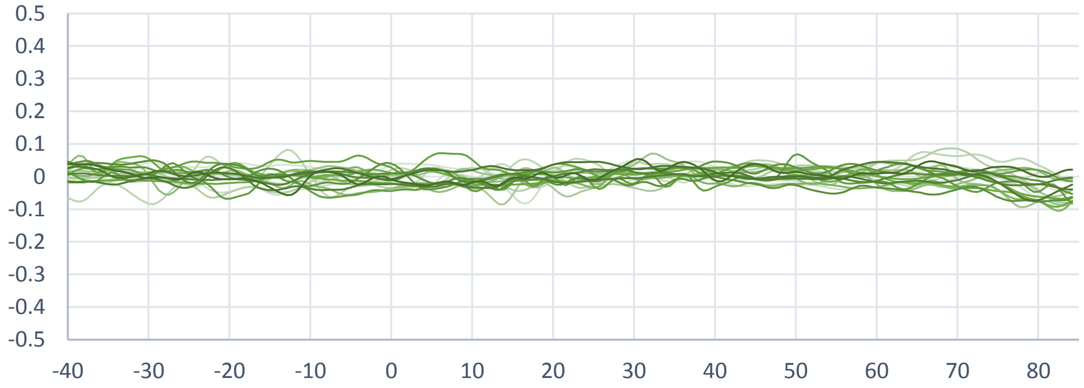
Fvs.T (ppb)



7x5 TCOCXO, Start-up -40C



Slope (ppb/C)



Mini OCXO evolution: Set Point Error Correction

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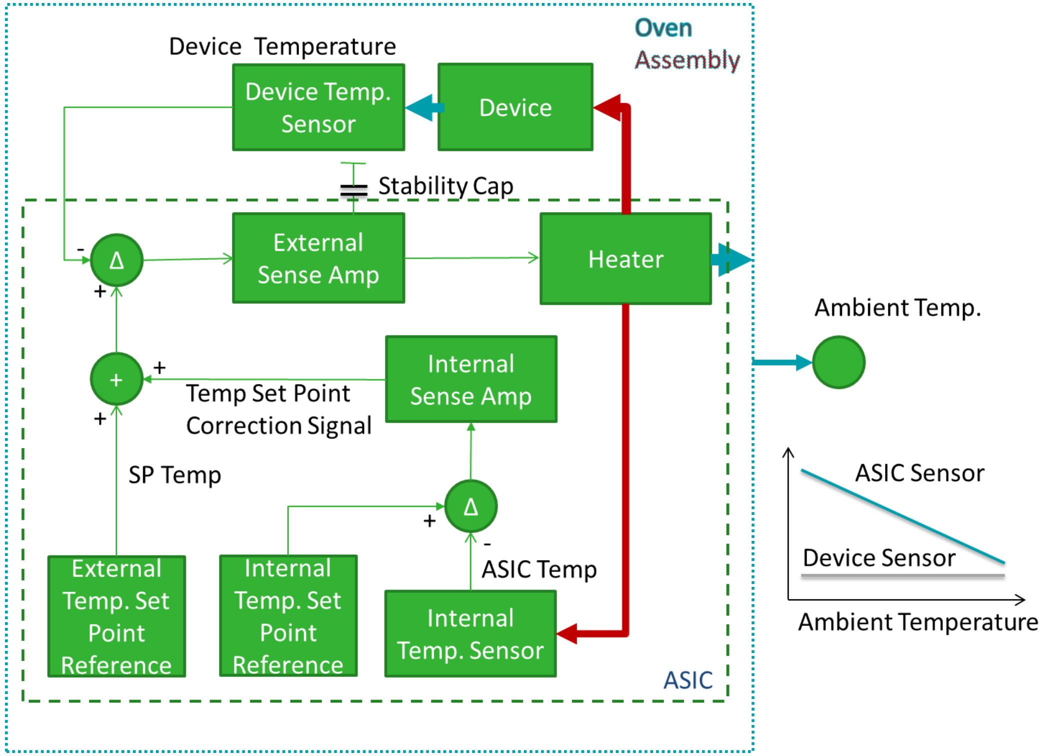
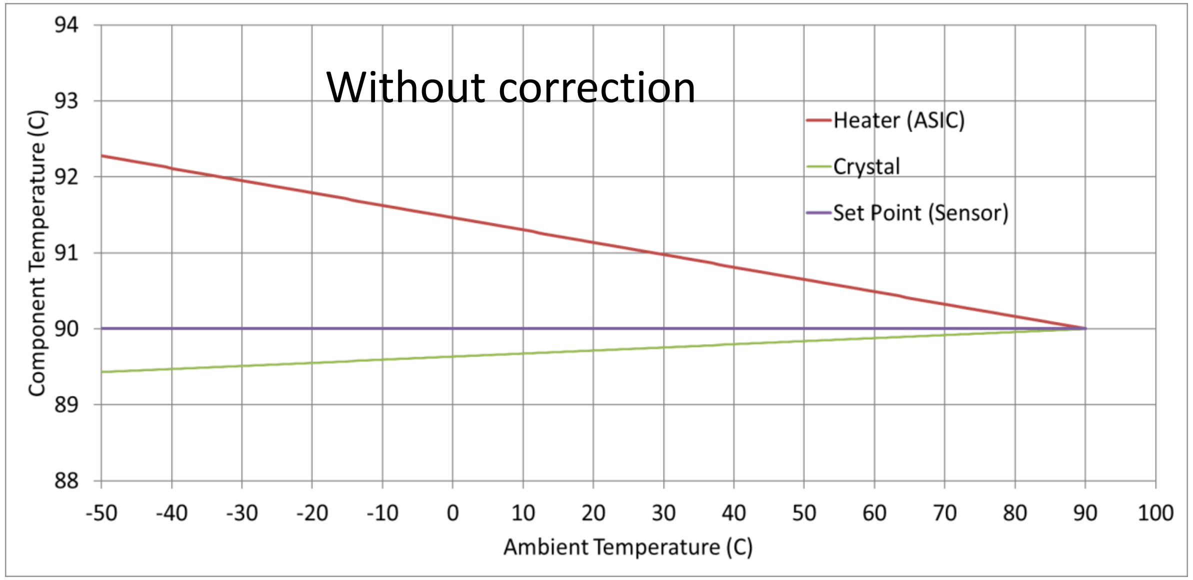
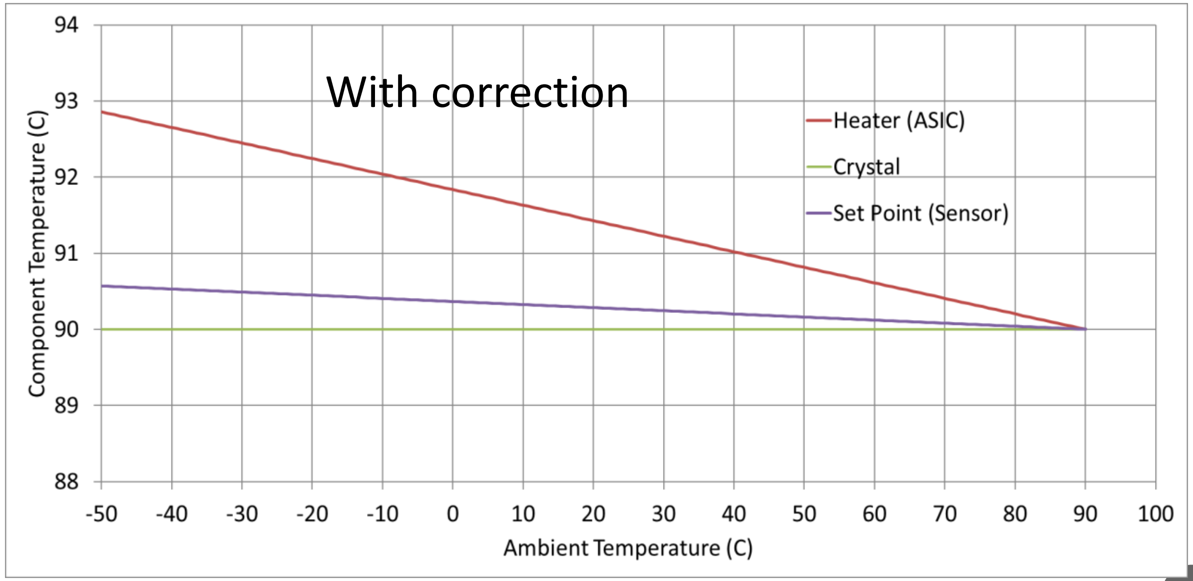
- **Set point error correction**
  - Senses ambient temperature and apply correction to the residual frequency error
  - Corrects the cause of the main frequency error
  - Takes stability down from 5ppb to < 1ppb

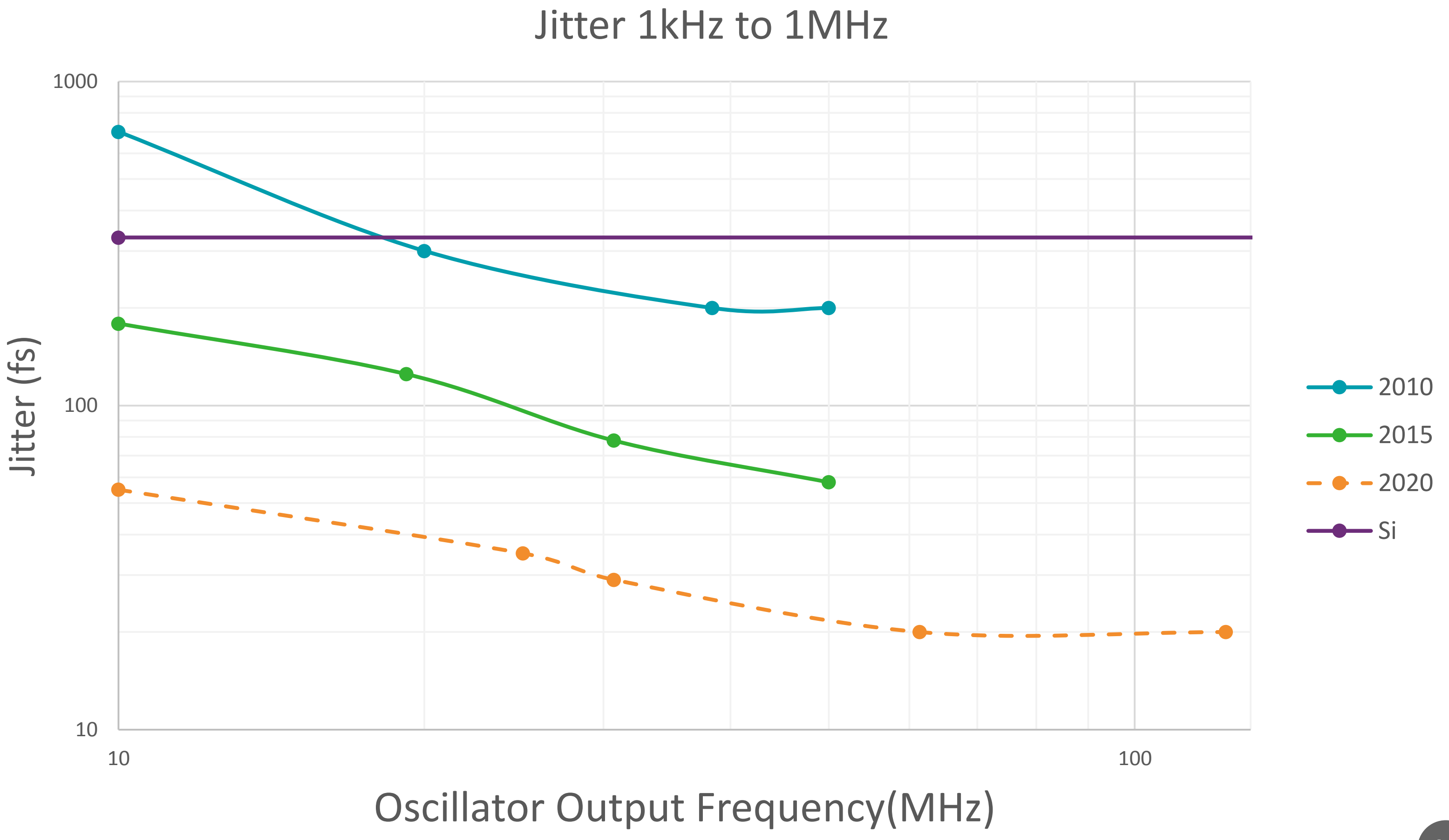






Mini OCXO Jitter Evolution

- **Improvements in ASIC technology**
  - Faster, lower noise processes
  - Oscillator and Output Buffer Phase noise floor improvement
    - -150 → -160 → -170 dBc/Hz
- **Higher frequency resonators**
  - Higher frequency SC-cut
  - Third overtone strip crystals
- **Phase Jitter**
  - Jitter floor (1kHz to 1MHz)
    - 200fs → 60fs → 20fs



Silicon vs Quartz

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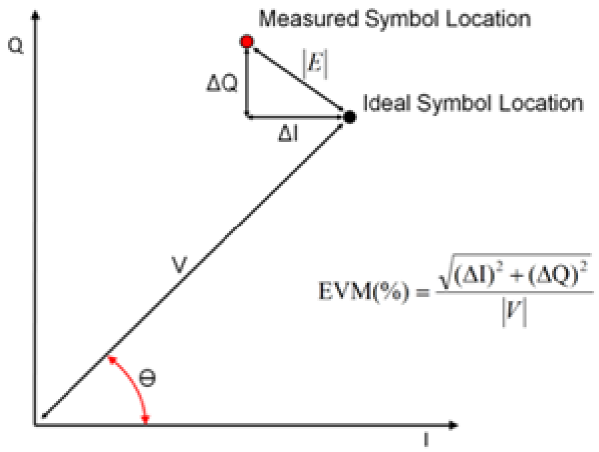
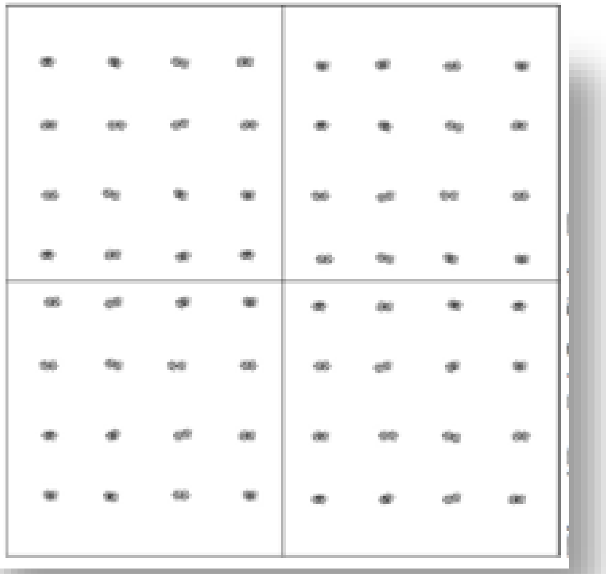
- **Silicon**
  - Not piezoelectric
  - Resonator electrostatic coupling
  - Lack of fine frequency adjustment
  - Lack of direct oscillator adjustment
- **TCXO/OCXO achieved by:**
  - Fixed frequency silicon MEMs oscillator
  - High resolution frequency adjustment via Frac–N PLL synthesiser
- **Temperature sensor**
  - Two resonators, one low temperature coefficient, one high temperature coefficient. Thermally coupled.
  - Difference frequency gives high resolution digital temperature measurement
- **Temperature Compensated Synthesiser(TCS)**
  - Stability is constant with output frequency
  - Jitter is constant with output frequency
    - Jitter relatively high, in the effective bandwidth

- **Quartz**
  - Piezoelectric, simple coupling
  - Large Resonator frequency range
    - 32kHz tuning fork to 2GHz SAW
    - Standard BAW resonators span ~1 to~ 600MHz
  - Higher Q resonator, even with higher coupling
  - Resonator has individual fine frequency adjustment in manufacture
  - Oscillator Adjustable in circuit (VCXO)
- **Stability very good, but traditionally gets worse as frequency increases**
- **Jitter relatively low and improves significantly as frequency increases**

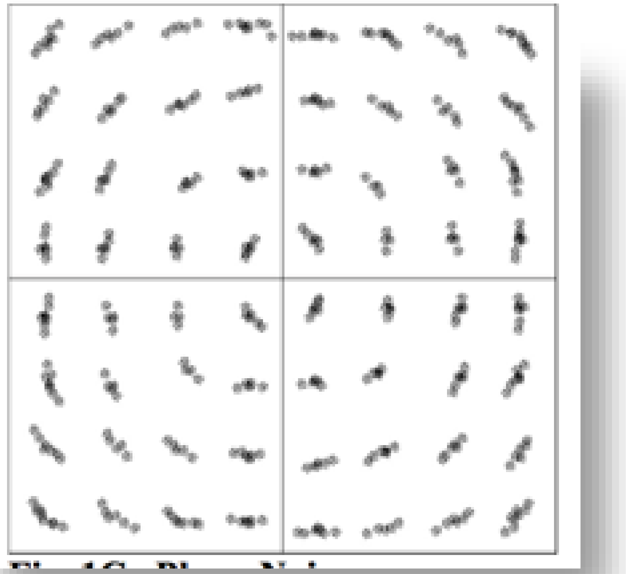
RRU Phase Jitter requirements

- **Drivers for phase stability, low jitter, EVM (Error Vector Magnitude)**
  - Higher QAM values 16,64,256 and Higher carrier frequency (<1GHz →3-4GHz→24-28GHz)
- **Imposes Requirements on the oscillator/pll multiplication chain**
  - Requirements for phase/time stability of <~100fs region over times of <~ 100us
  - Oscillator chain, frequency multiplied up to the carrier/modulation rate.
  - Integral of phase spectral density over a bandwidth





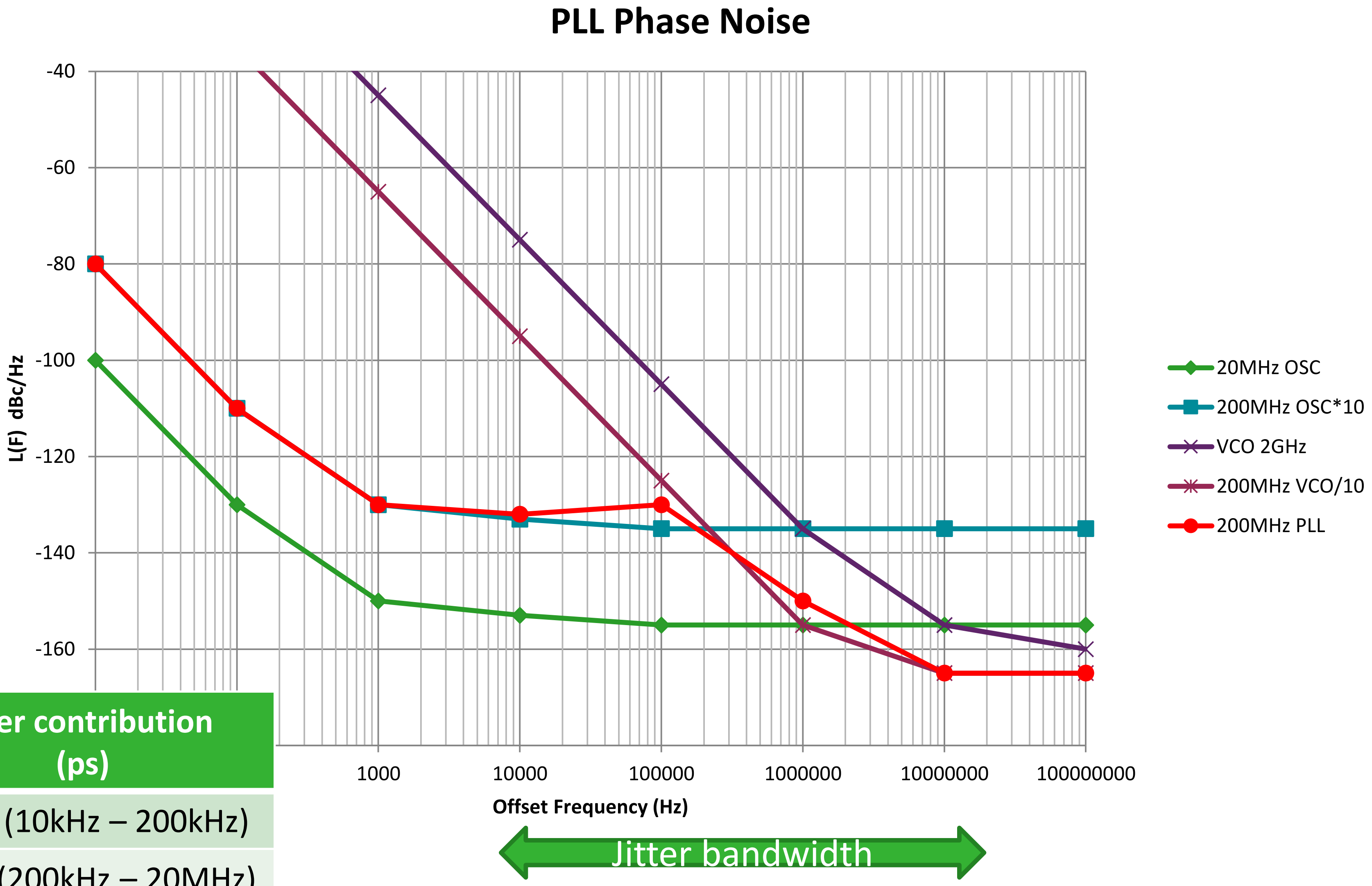
QAM 64 Ideal Constellations



Constellations with high phase noise

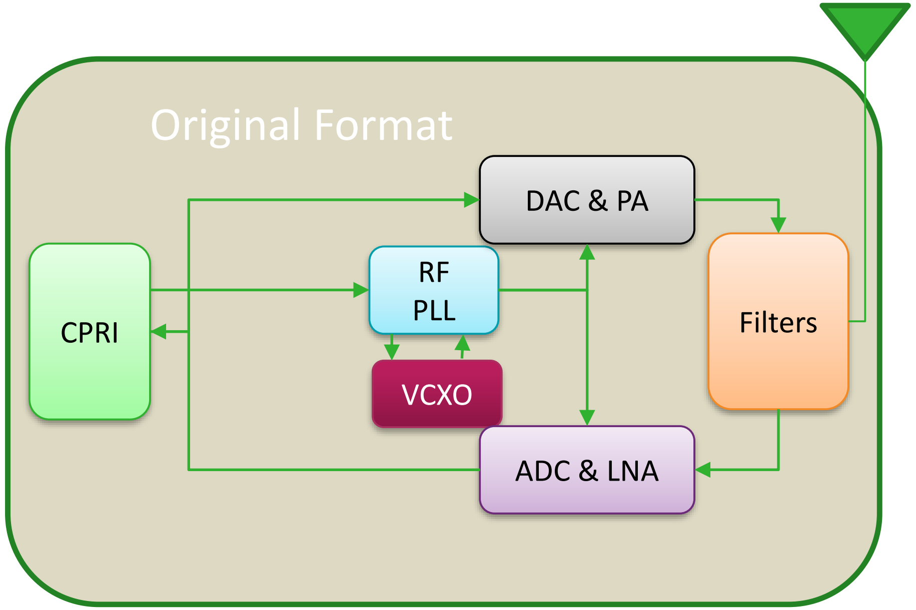
Oscillator/PLL chain - multiplying the frequency up

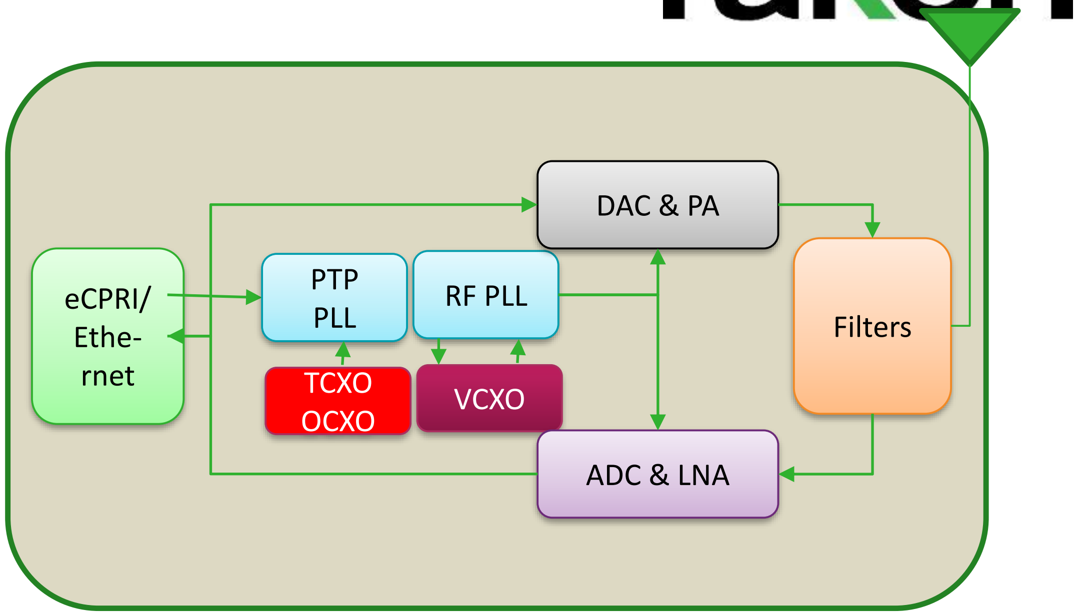
- Idealised example
- Locking high frequency VCO to low frequency crystal oscillator
  - Example 200MHz output from 20MHz TCXO and 2GHz VCO
    - TCXO 20MHz
    - TCXO * 10
    - VCO 2 GHz
    - VCO /10
    - 200MHz PLL output



Oscillator	Jitter 10kHz- 20MHz (ps)	Jitter contribution (ps)
TCXO	0.89	~0.08 (10kHz – 200kHz)
VCO	1.41	~0.08 (200kHz – 20MHz)
PLL	0.17	~0.17(10kHz – 20MHz)

5G Remote Radio Unit. Timing evolution





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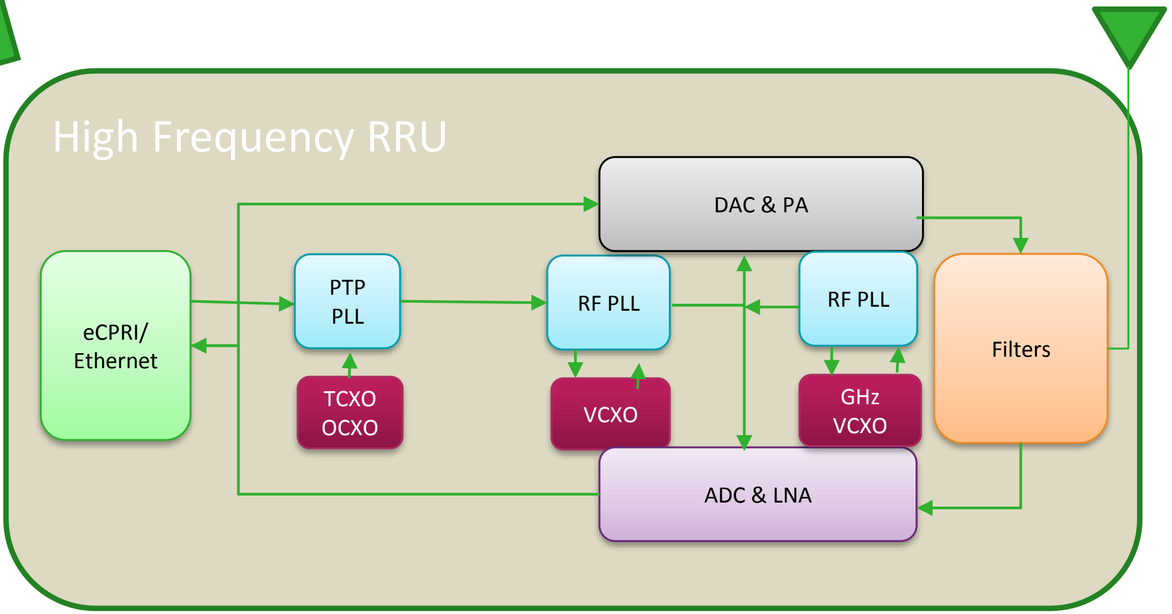


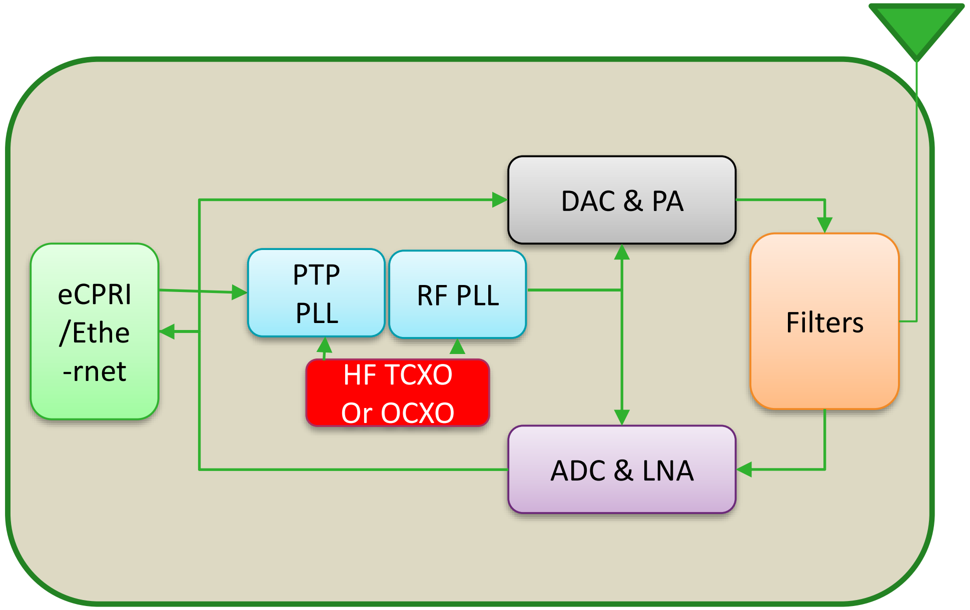
- **Packet interface into RRU necessitates protocol layer timing recovery**
- **Packet timing recovery needs higher stability reference clocks**
- **Higher spectral frequencies need lower phase noise reference clocks – GHz VCXOs**

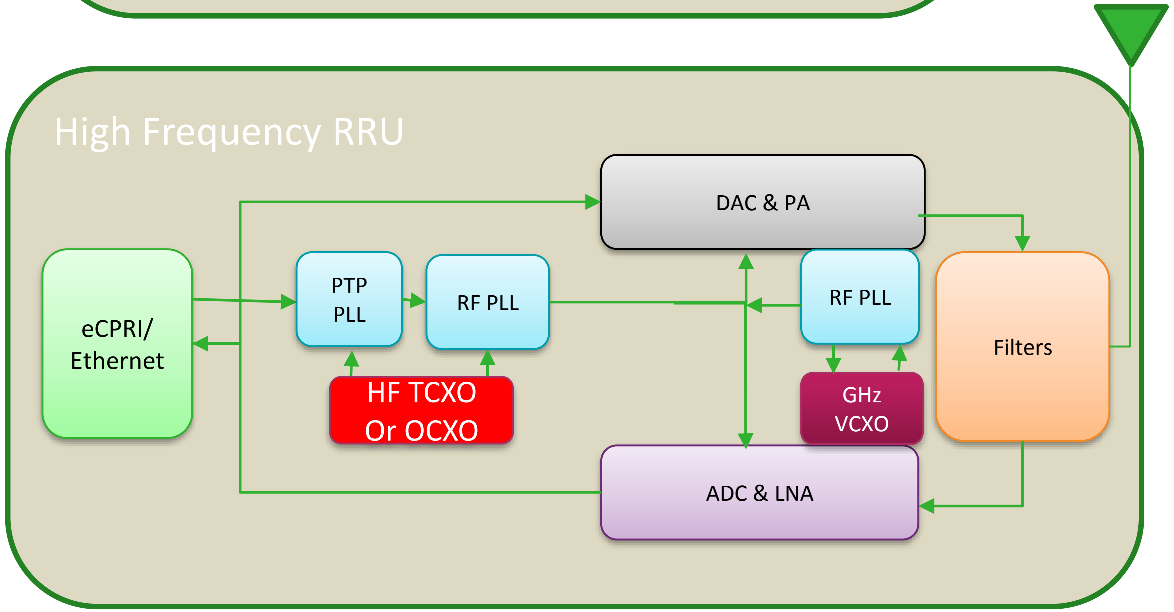
Multiplying the frequency up

- **Jitter stays the same with idealised frequency multiplication/division**
- **Lower frequency oscillator only contributes up to PLL loop bandwidth**
  - Jitter should be specified for appropriate bandwidth, probably around 1kHz to 1MHz
  - Higher Q VCO, allows lower loop bandwidth, reduces jitter of composite PLL output
- **May have multiple loops, jitter attenuators**
  - GHz VCO, locked to high frequency VCXO/XO, locked to low frequency TCXO/OCXO
  - High GHz VCO, locked to GHz VCXO/XO, locked to high frequency VCXO/XO, locked to TCXO/OCXO
- **Can save costs if simplified, remove high frequency VCXO/XO and go directly from TCXO/OCXO to GHz VCO**
  - Requires: Very Low jitter, high stability reference oscillator together with very good VCO/PLL

The future RRU oscillator?

- **Lower jitter higher stability TCXO and OCXO options available now and set to improve substantially**
- **Can combine both the low jitter and high stability into one oscillator**
  - High frequency low jitter TCXO or OCXO
- **Exact requirements for time and frequency sync. performance of local oscillator, still evolving:**
  - Heavily dependent on known quality of interface to RRU. Input specification.
  - Future output constraints, tighter time and phase tolerances.





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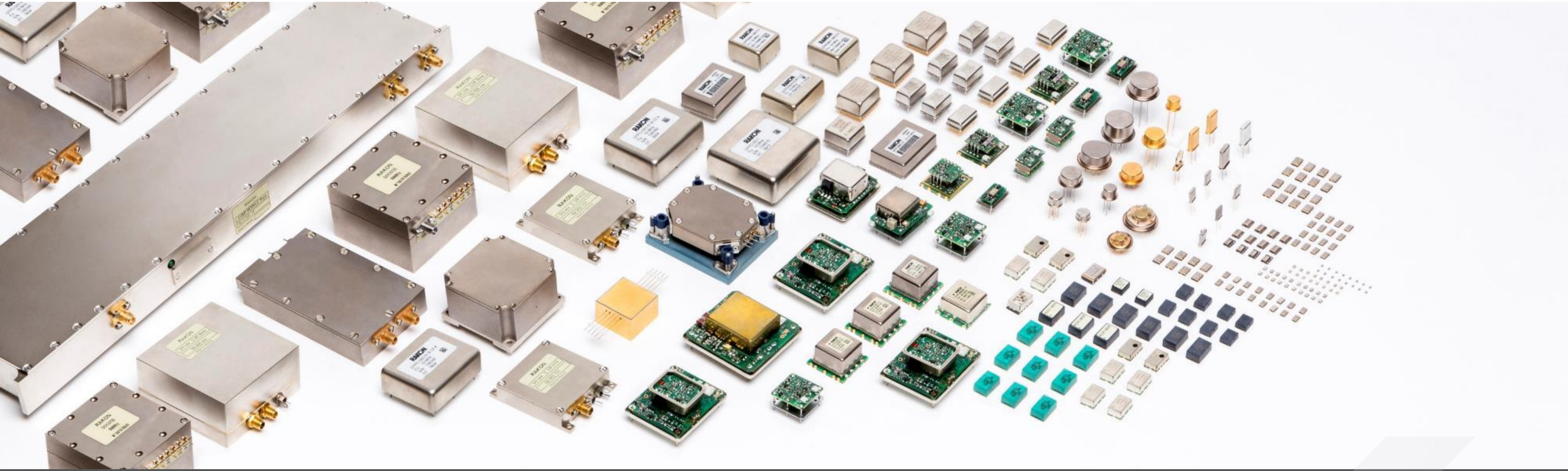

ITSF 2019

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