WSTS 2018 –

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Enabling the connected future

Hybrid OCXO as synchronization reference clocks addressing harsh environmental conditions

Electronic Circuits and Extreme Environments

- In this presentation, extreme (harsh) environments refers to
  - Extreme temperatures
  - Temperature Cycles
  - Shock and Vibration

- Next generation Transport & Mobile equipment demand lower profile, higher performance
  - Outdoor environments with temperature swings

- **=> Components operating at higher temperatures and harsher environments are required to address the thermal requirements of next generation equipment.**

High temperature OCXO…Where?

- **5G wireless Equipment**
  - The dense deployment of 5G demands modular equipment configurations.
  - Outdoor – Massive MIMO RRH – Classic example
  - Weatherproof outdoor equipment requires fan-less, sealed enclosures designs

- **Front-haul/backhaul & Transport Equipment**
  - Massive power hungry devices (10s of Ks of Watt) overall
  - Modularity enforces compact layout of high power elements on a Printed Circuit Board, introducing higher temperature levels
  - PCB temperatures >80 degC ranges

- **Data center equipment**
- **Industrial environments**
  - Inherently harsh environments

However moving to higher operating temperature system has some repercussion on overall reliability

This can be illustrated by **Arrhenius law.**

What does Arrhenius law mean?

- The base failure rate is usually expressed by a model relating the influence of electrical and temperature stresses on a part.
- One of the most characteristic parts of many models is the relation between temperature and failure rate. These models use thermal stresses in a form related to the Arrhenius Law.

$$A_T = e^{-\left(\frac{E_{aa}}{k}\right)\left(\frac{1}{T_1}-\frac{1}{T_2}\right)}$$

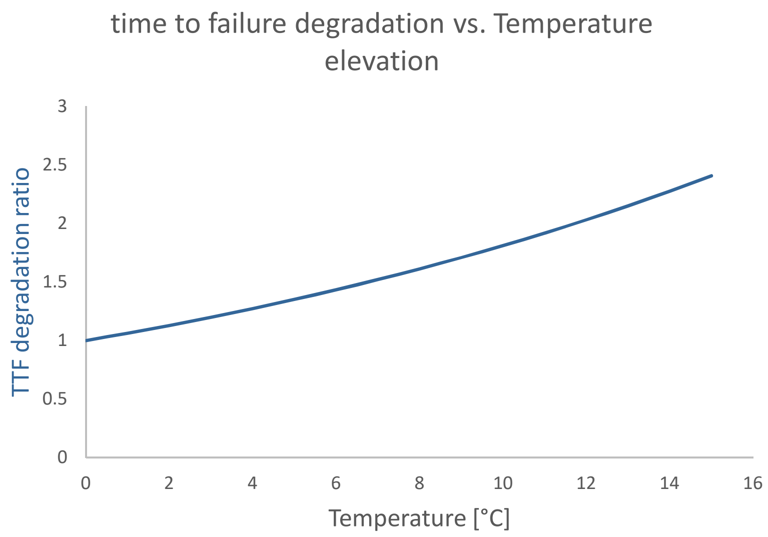
Where:

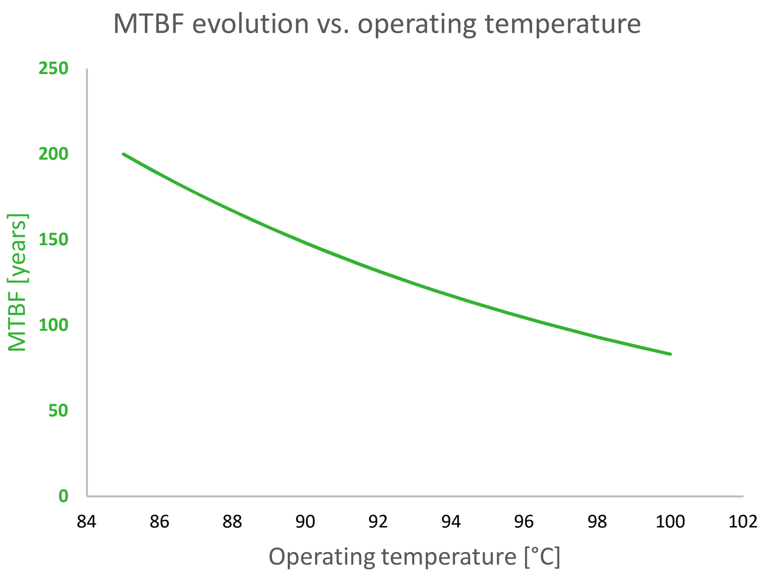
A_T	is the acceleration factor due to changes in temperature;
E_{aa}	is the apparent activation energy (eV);
k	is Boltzmann's constant (8.62×10^{-5} eV/K);
T_1	is the absolute temperature of the test (K);
T_2	is the absolute temperature of the system (K).

translating Arrhenius law to reliability

The hotter the worse the **reliability** will be …

Indeed:





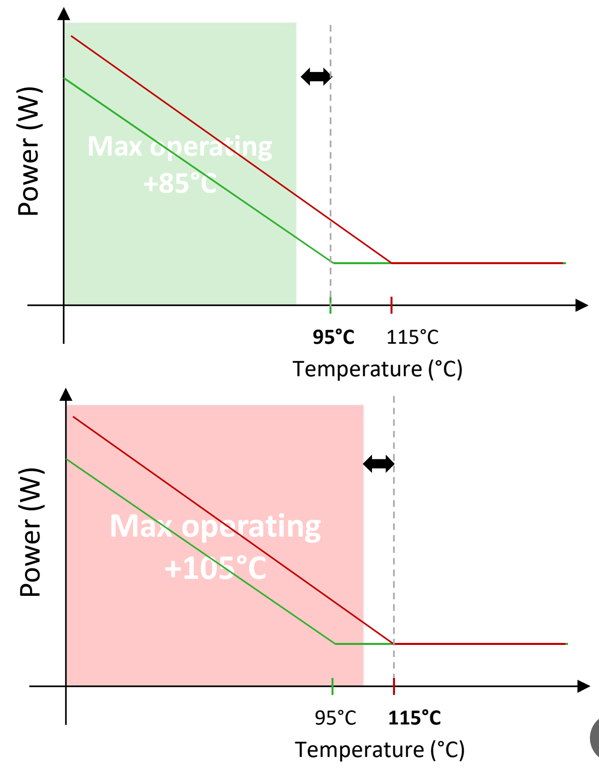
How address high temperature design?

- Due to internal residual power dissipation (oscillator, voltage regulation, buffer stage)

A **minimum offset** between the maximum surrounding temperature and the oven temperature shall be maintained

Depending on supply voltage, a 5°C offset is considered for safe operation
A 105°C environmental temperature means a 110°C oven temperature

Whatever temperature is, OCXO will be always at the hottest operation!



How achieve high reliability oscillator?

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- **Reducing the number of components** will mathematically improve the MTBF as it does statistically reduce the number of failure rate λ

$$MTBF = {}^{1}/_{\lambda}$$

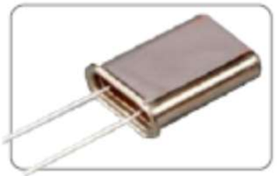
- As per **UTE-C80-810**

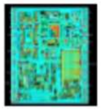
- An empiric relationship express the global failure rate : $\lambda = \lambda_a \times \lambda_b \times \lambda_c$
  - λ_a= failure acceleration due to temperature and stress
  - λ_b= acceleration due do encapsulation failure (thermal cycles)
  - λ_c= acceleration due to accidental overload

- **Dedicated ASIC** will address this component count reduction as well as the packaging question .

Why Hybrid OCXO?

- **Putting together the best of the 2 worlds…!**





- Ageing performance
- Frequency recovery/retrace
- Overal thermal and mechanical sensitivity

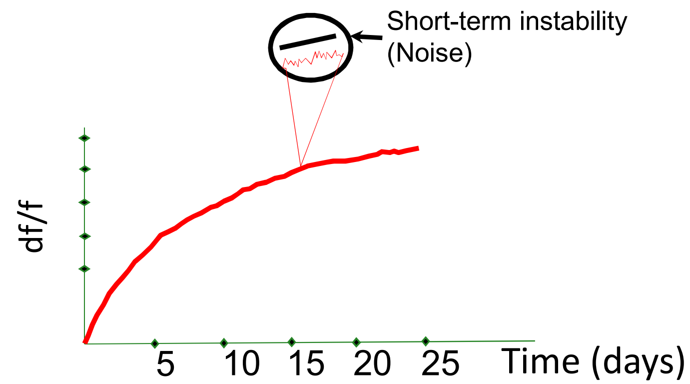
- High integration
- High reliability
- Power saving

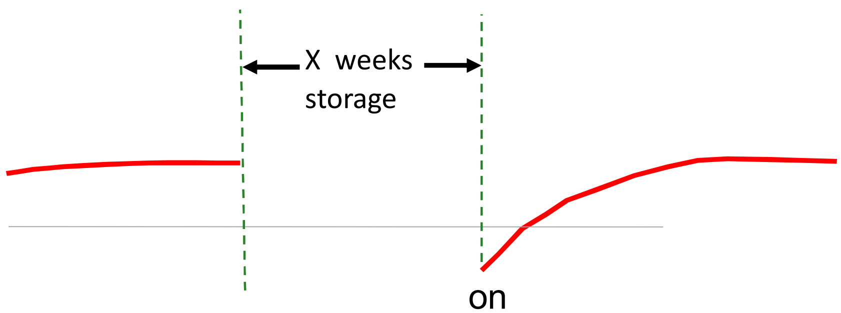
What about Hybrid OCXO performance?

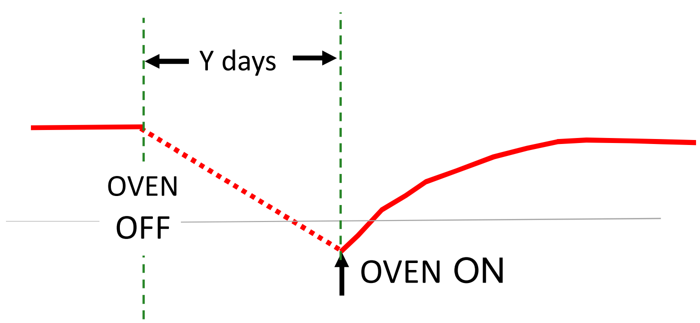
As network are more and more demanding for **time keeping performance**, more than ever XTAL oscillators need very high stability

What are the criteria that condition part final OCXO performances?

- Ageing
- Retrace
- Frequency recovery
- Short term stability

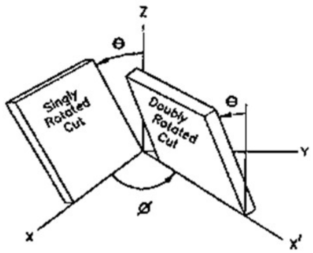


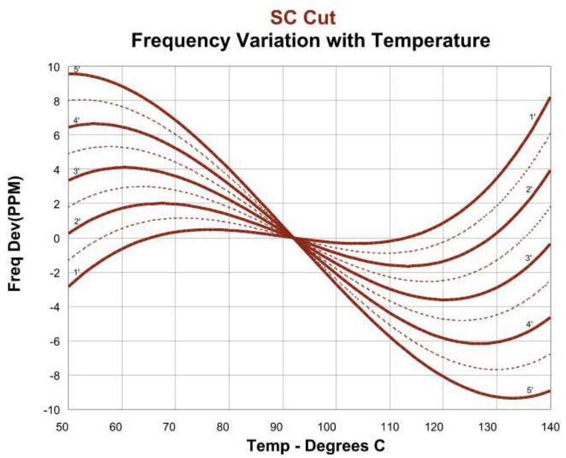




What about XTAL?

- **Thermal** sensitivity





Thermal sensitivity is driven by Xtal cut.

Double rotated **true SC** cut are offering much better performance over temperature.

$$\frac{\Delta f}{f} = \alpha(T - T_0) + \beta(T - T_0)^2 + \gamma(T - T_0)^3$$

Need for temperature minimizing….

- **Thermomechanical** constraints

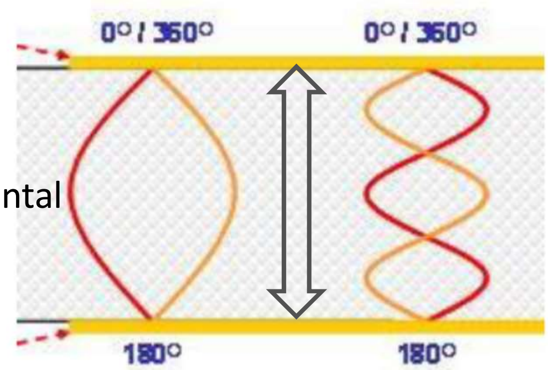
- As a second order of magnitude, temperature is no more the sole frequency instability contributor. The constraints brought by the stress onto the XTAL blank does contribute to the frequency instability

Benefits of 3rd overtone metal XTAL package?

- Metal package Cold Welding CW can guarantee **2nd order vacuum** over lifetime
  - Very low mass loading long term ageing/frequency drift (the simple weight of any material onto Xtal will affect frequency drift)

- **3rd overtone**, means that for same end frequency, XTAL blank will be 3 times thicker
  - Better quality factor Q
    - Phase Noise (close to carrier)
    - Short term stability (Allan Deviation)
  - Better ageing
    - Reduced mass loading effect
    - Less sensitivity to mechanical holder

10MHz Fundamental mode



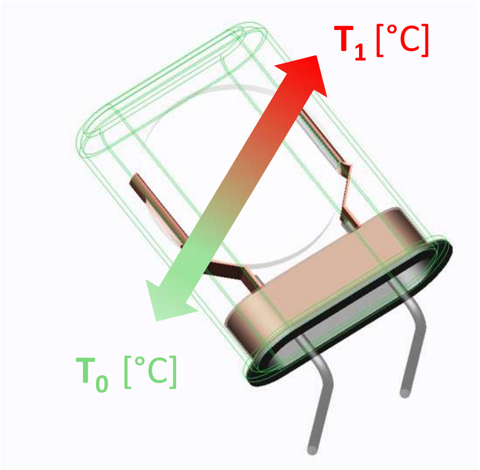
3.3333MHz Fundamental =10MHz 3rd OT

ASIC OCXO challenge

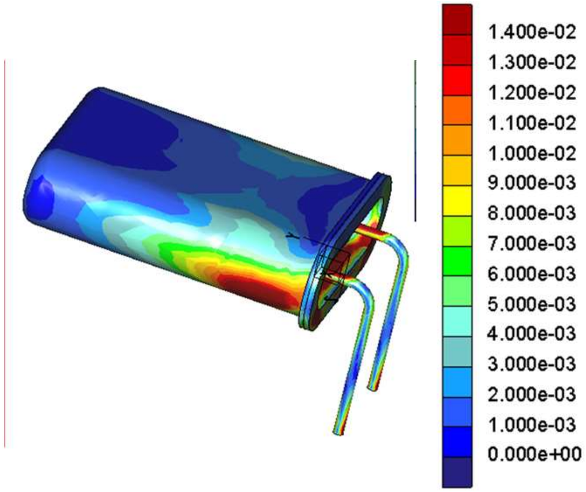
- However getting ppb range OCXO is not matter of thermal sensitivity only…

Even tough XTAL blank becomes lower, still temperature across package (thermal gradient) remains

The thermal **expansion and contraction** due to temperature are bringing some mechanical stress materialized by colors indicating the constraint magnitude [MPa]



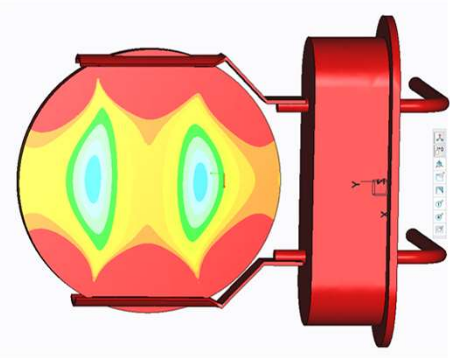
Temperature gradient



Mechanical constraints

ASIC OCXO challenge

- Computing **mechanical** constraint to … **Frequency** deviation



This can be modelized as Xtal mechanical constraints and further computed to frequency shift

$$\Delta f = [\alpha_i] \times [T_1, T_2, T_3, T_{4,} T_5, T_6]$$

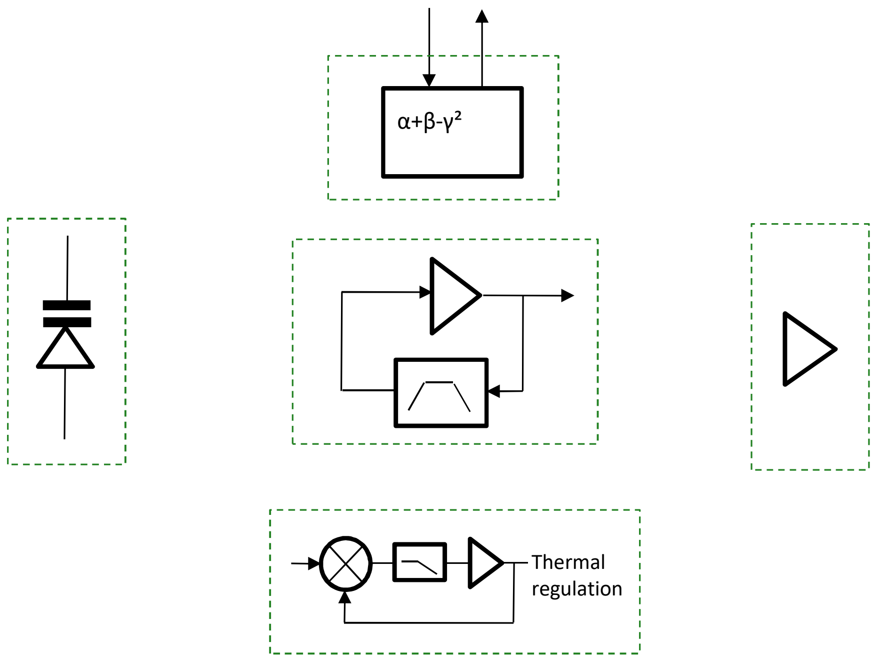
When XTAL blank temperature becomes low, then the frequencies instabilities are due to residual thermomechanical constraint.

the contribution for metal package XTAL may reach **several ppb**, which is similar order of magnitude of pure temperature contribution

Oscillator topology

ASIC is integrating multiple functions

- Thermal regulation
- Oscillator circuit
- Output buffer
- Tuning circuit
- Multiple compensation circuit

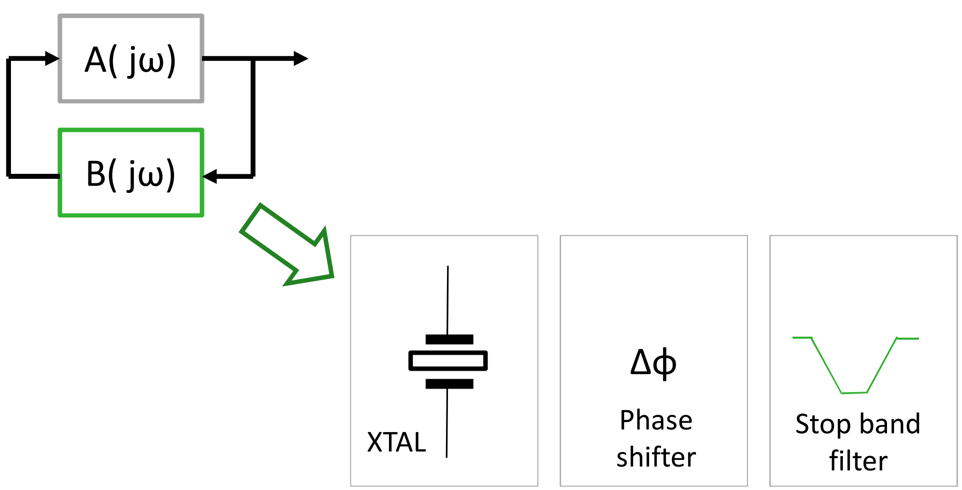


ASIC OCXO challenge and limitation

Oscillator can be seen as an

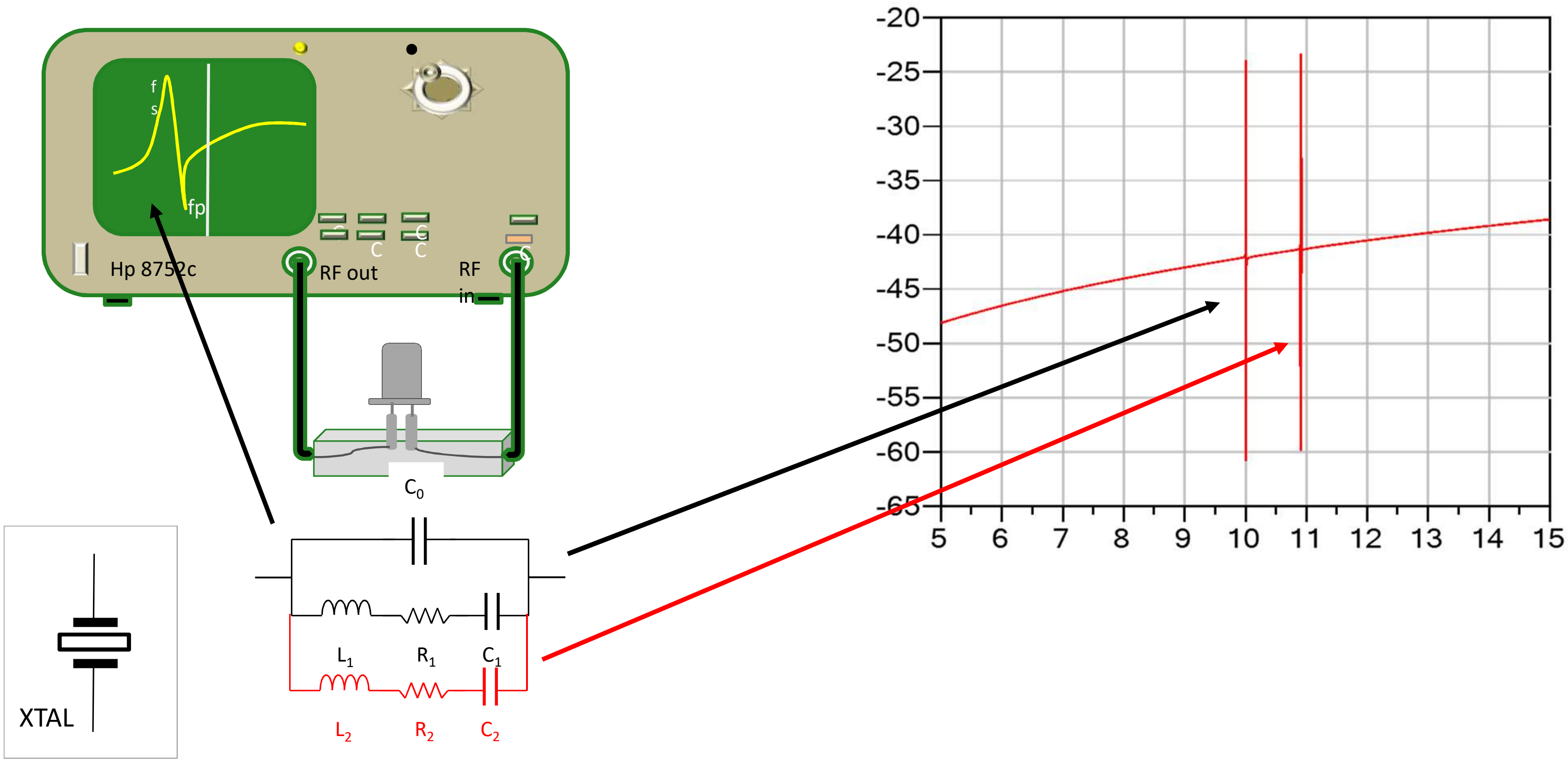
- **direct amplifier** A(jω)
- feedback loop made of **bandpass filter** B(jω)

This simple approach is however more complex as the feedback loop is made of:



ASIC OCXO challenge

- C mode is the oscillation mode but spreading analysis windows show an unwanted **B mode**



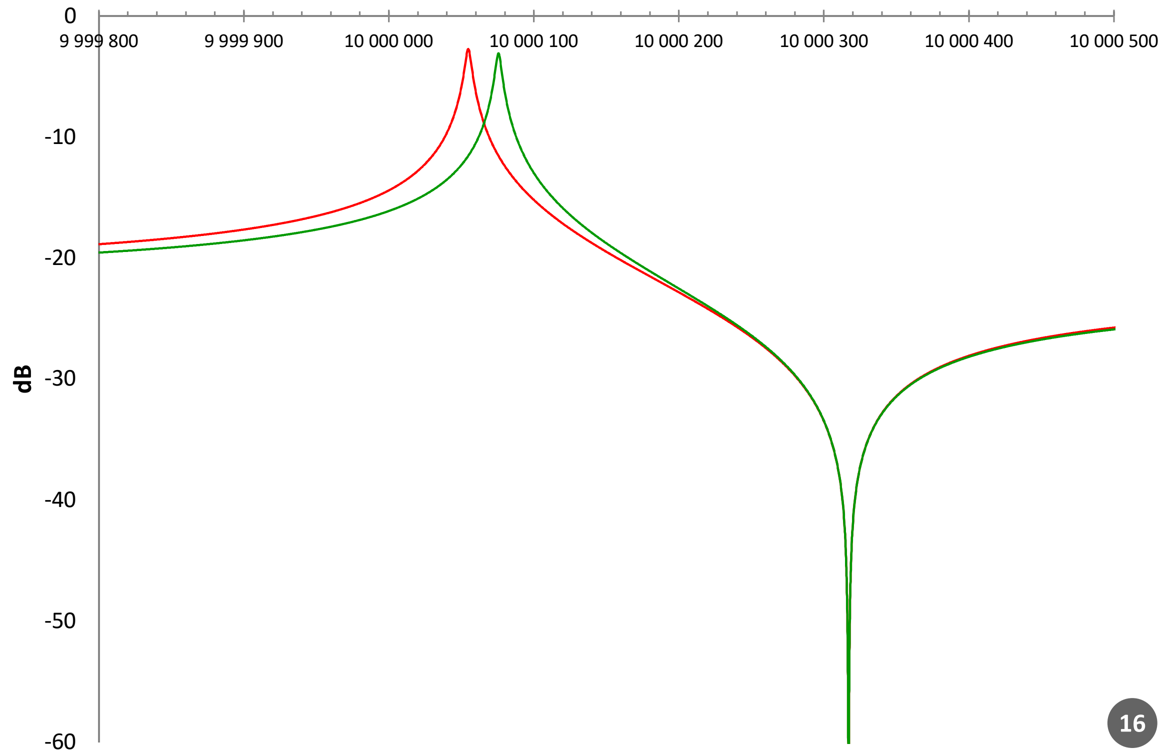
ASIC OCXO challenge and limitation

- **B mode limitation due to round XTAL**

Close frequency means that a sharp B mode trap filter has to be implemented
Need for large external coil with high quality factor
Temperature sensitivity is **~150ppm/°C**

- **Load capacitance sensitivity**

In addition stray capacitance in the oscillation loop are inducing frequency shift



Hybrid OCXO performances today

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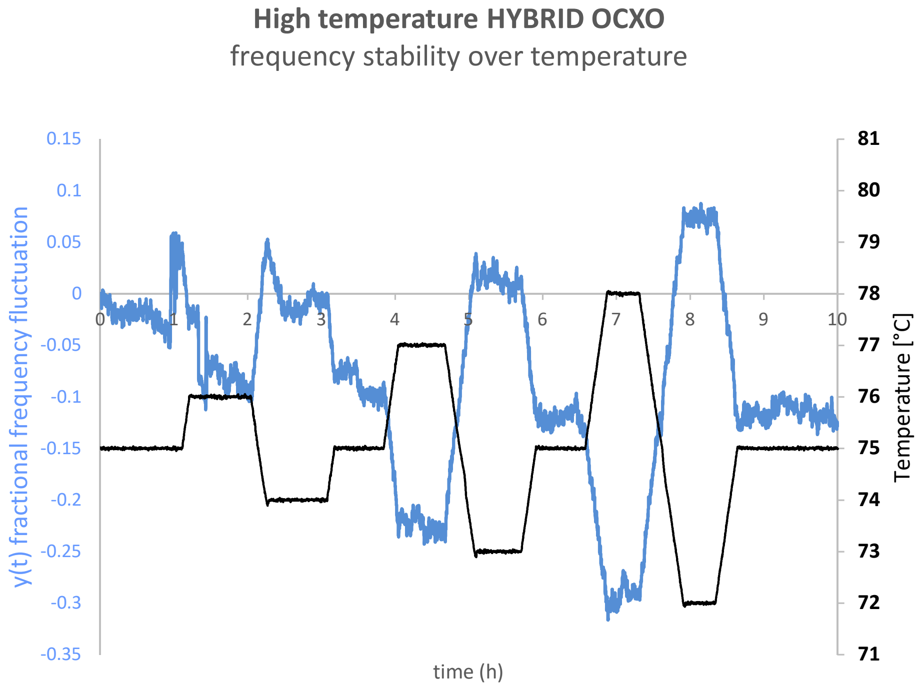
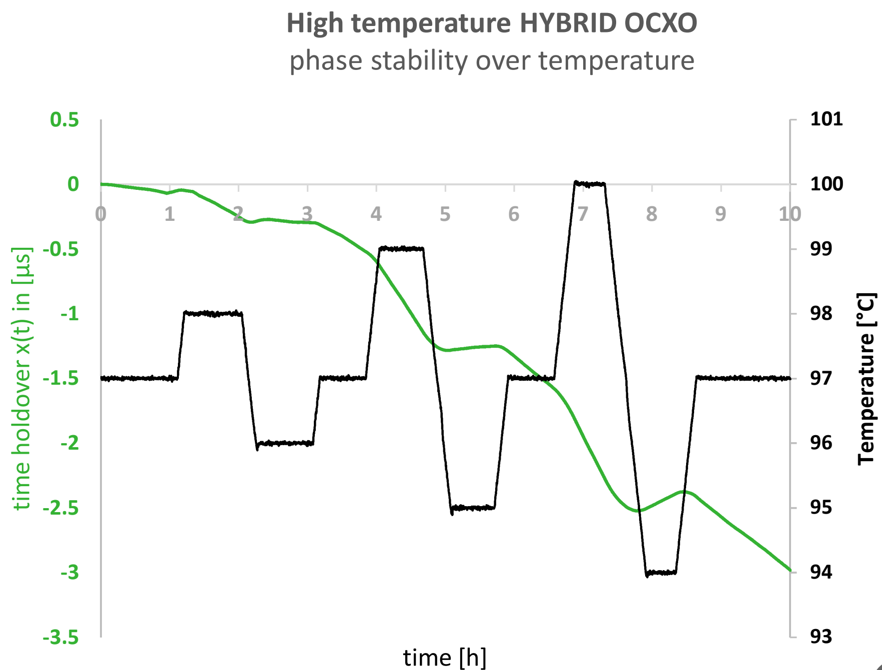
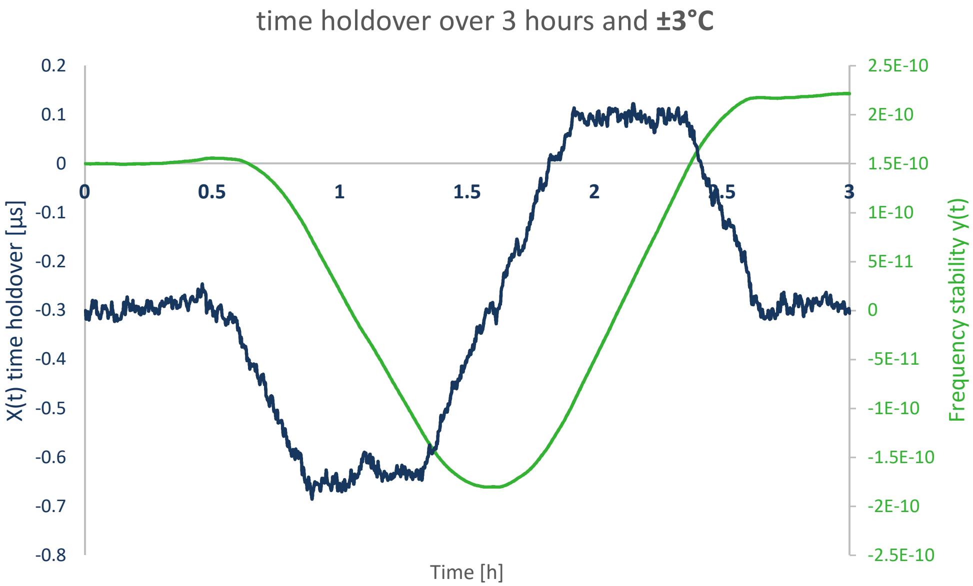
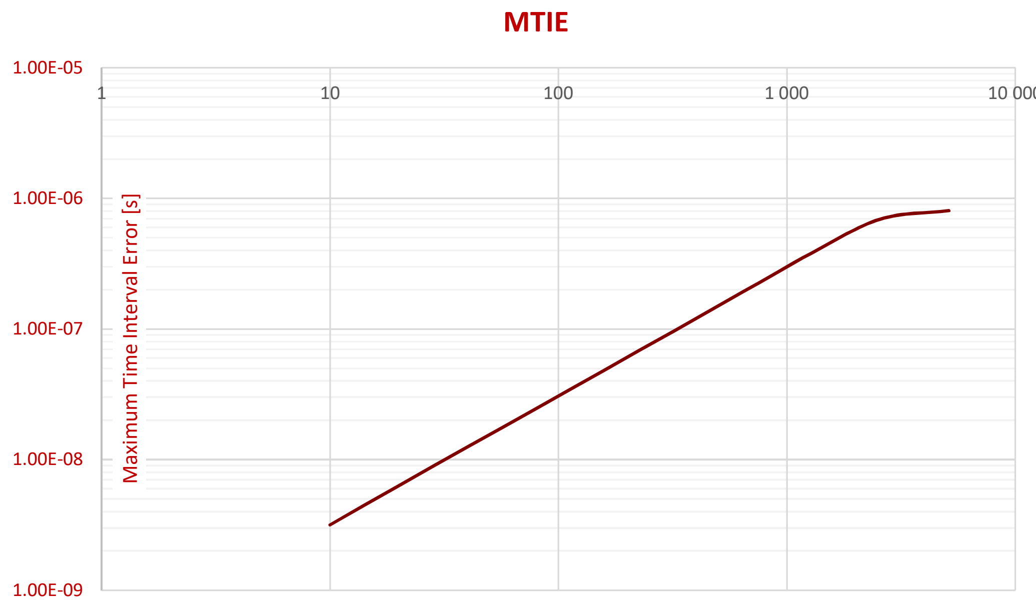




Hybrid OCXO performance overview

Time keeping ability





Conclusion

- Hybrid OCXO are a technical response to address harsh environmental conditions under high temperature
- Advanced OCXO structure simulation has lead to optimized hybrid structure design
- ASIC based structure is bringing huge benefits with respect to reliability under high temperature
- Metal package XTAL are exhibiting excellent thermal and thermomechanical performances
- µs times holdover may be achieved at high temperature over limited span

Hysteresis is currently limiting factor further improvement are under progress…

THANK YOU!

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