Design Challenges and Solutions in Achieving Ultra-Low-Power OCXO's for Portable and Unpowered Environments

rakon

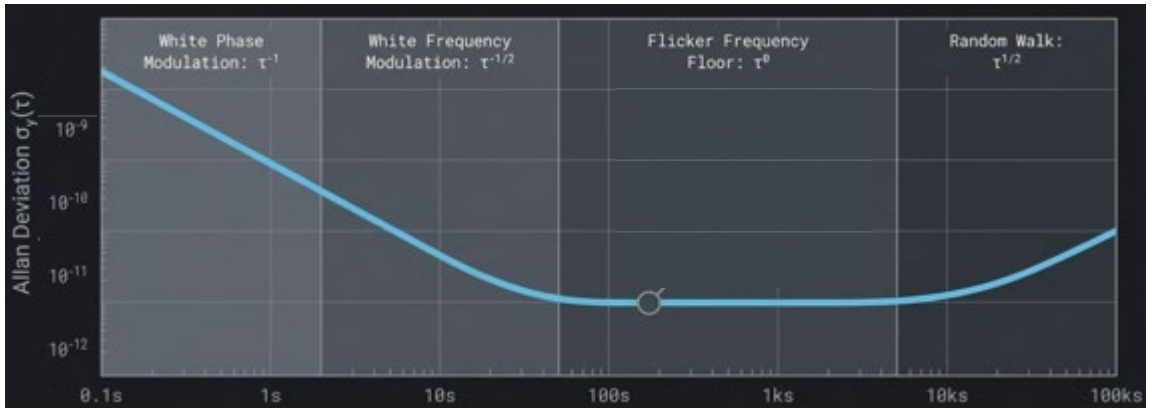
SWaP-C at Edge

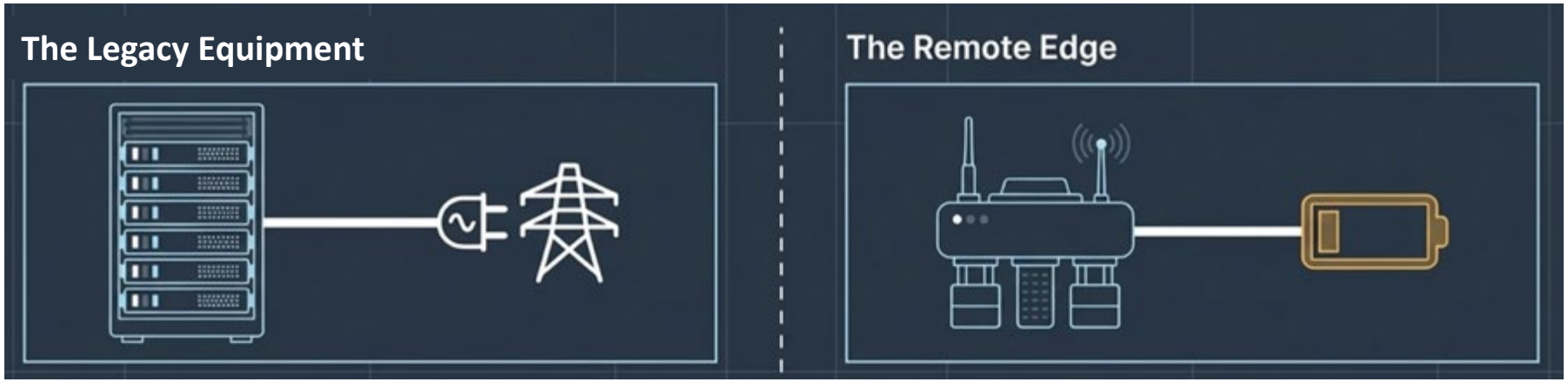
Stability Target: Stratum 3E level stability

- 10ppb temperature stability across operating temperature
- 1ppb/day ageing performance

ADEV performance

- time-domain frequency stability e^{-11} /1-100s

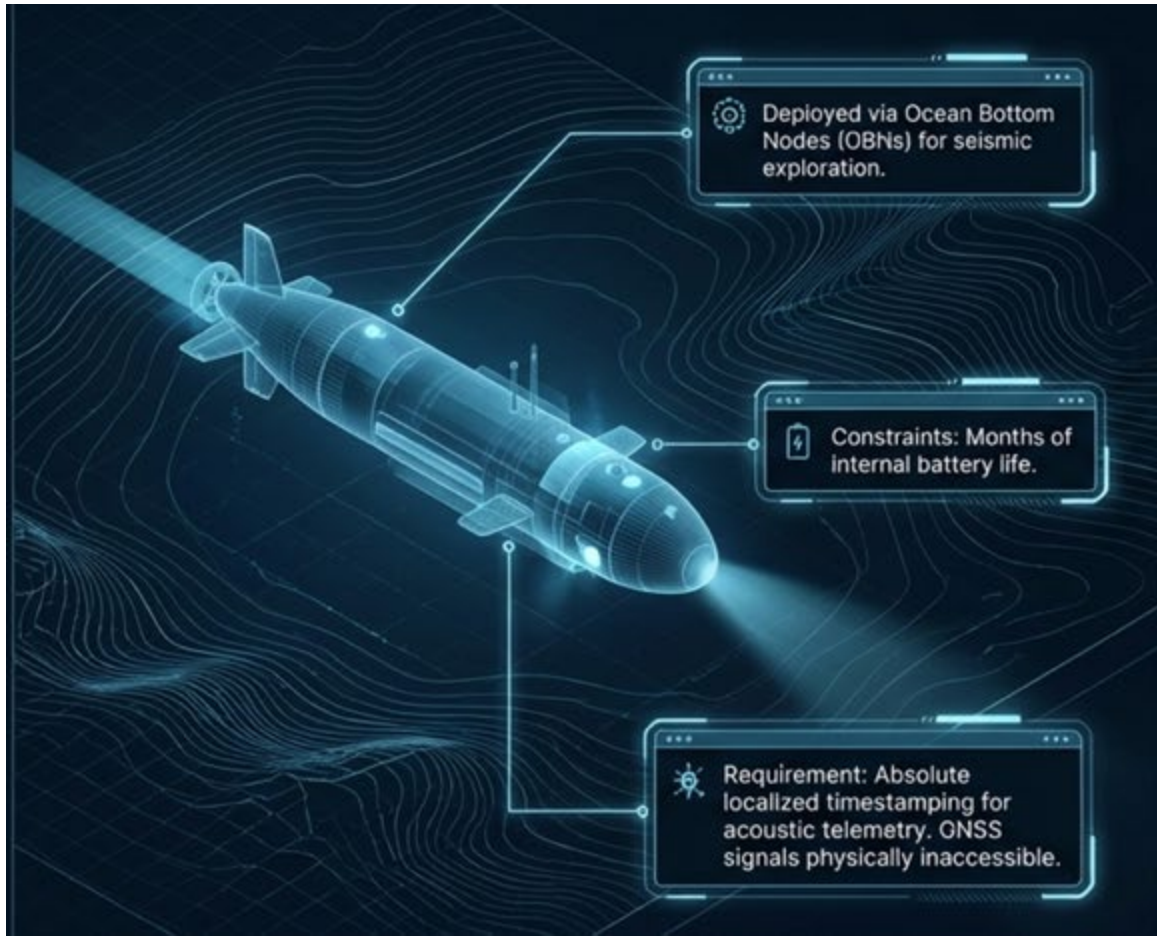




1.5W - 2.5W OCXOs

Target 150mW

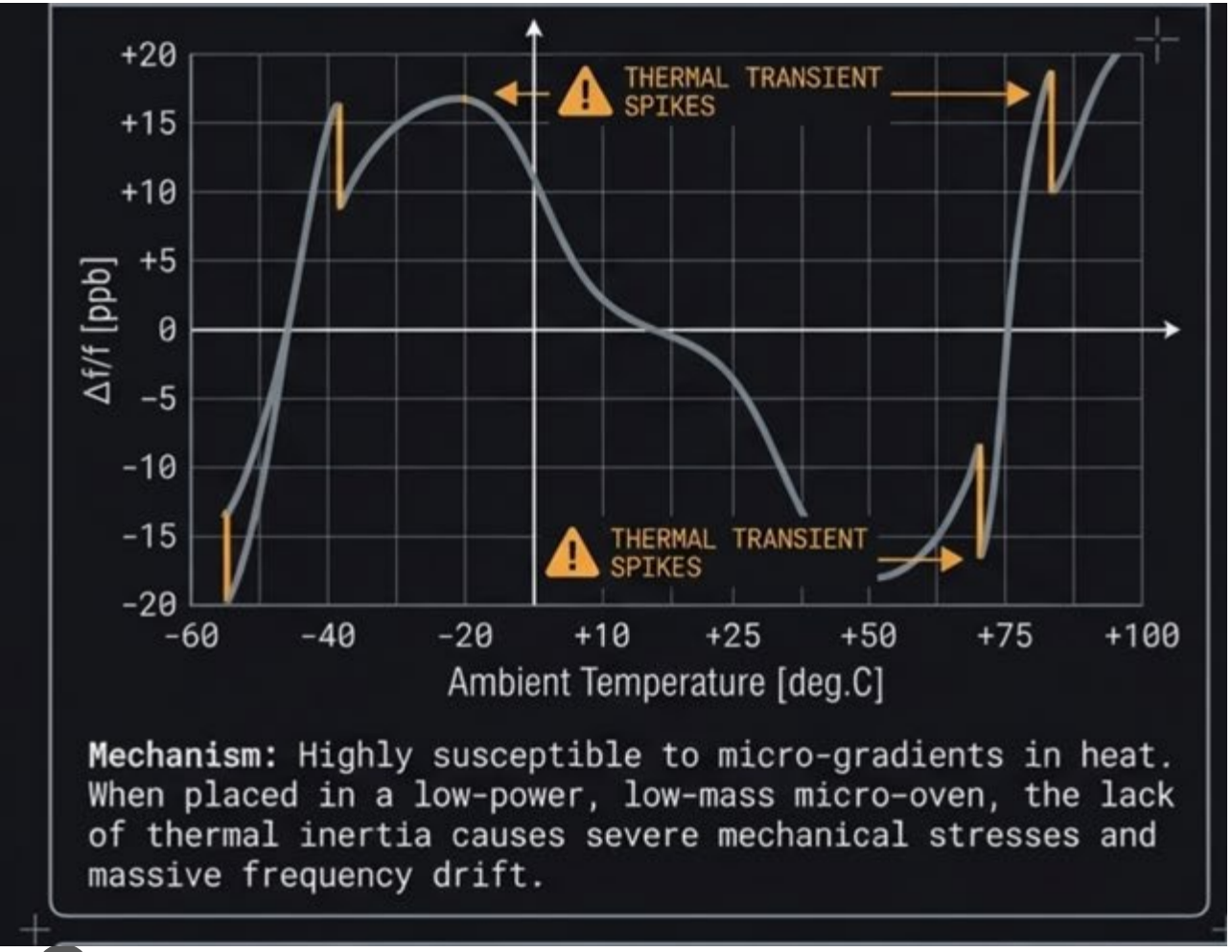
Emerging applications



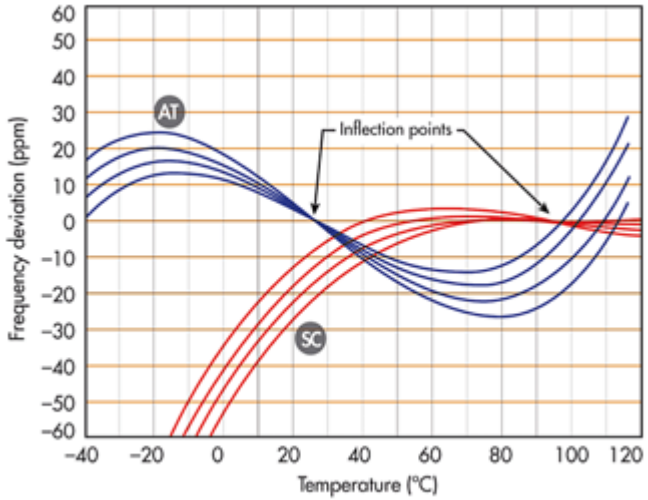
- Autonomous Underwater Vehicles, Man Pack Radios, Automated Guided Vehicles, Drones

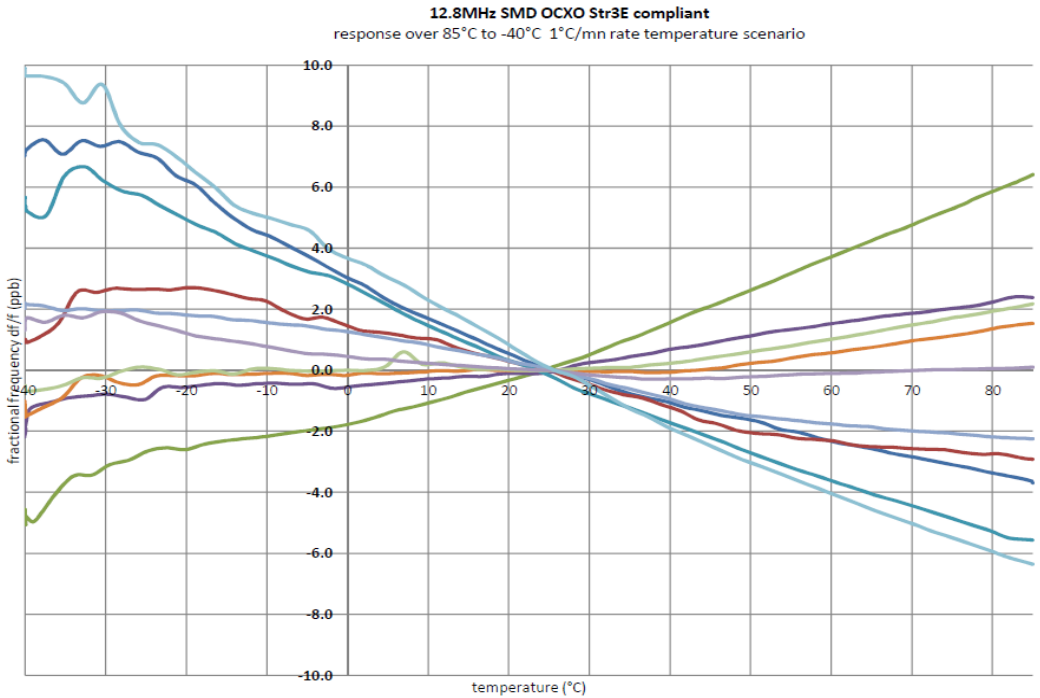
Crystal selection

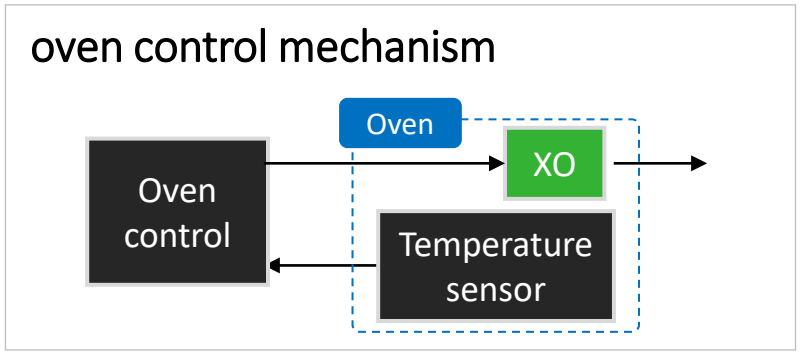
AT-Cut Crystal

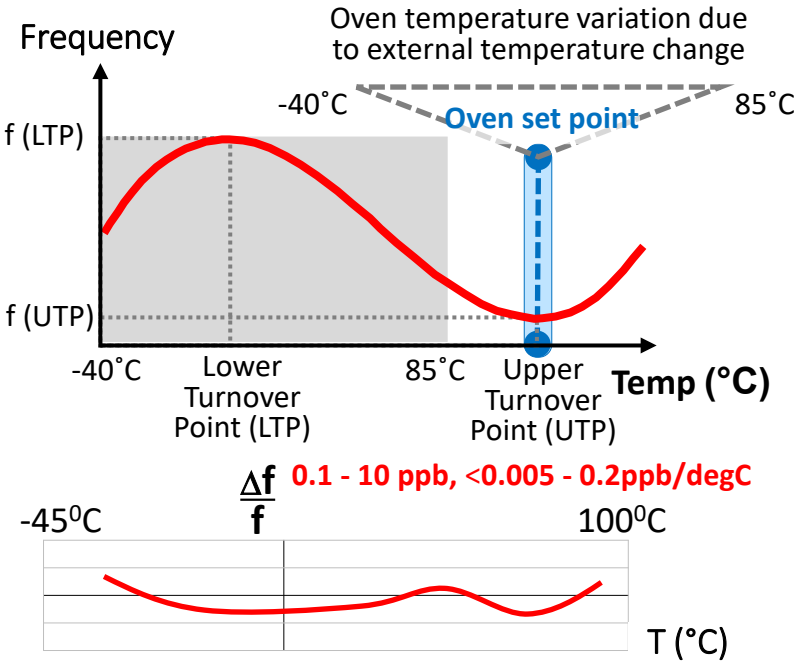


Oven Control



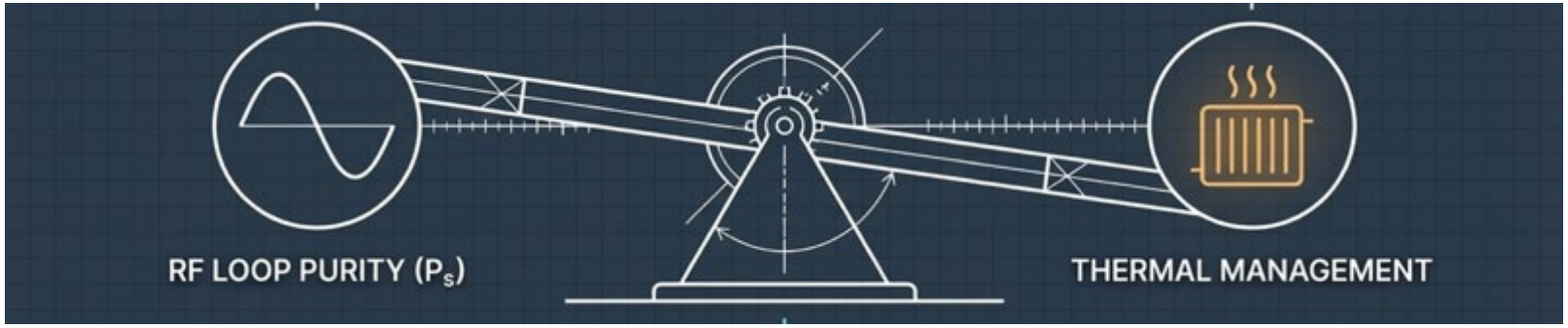


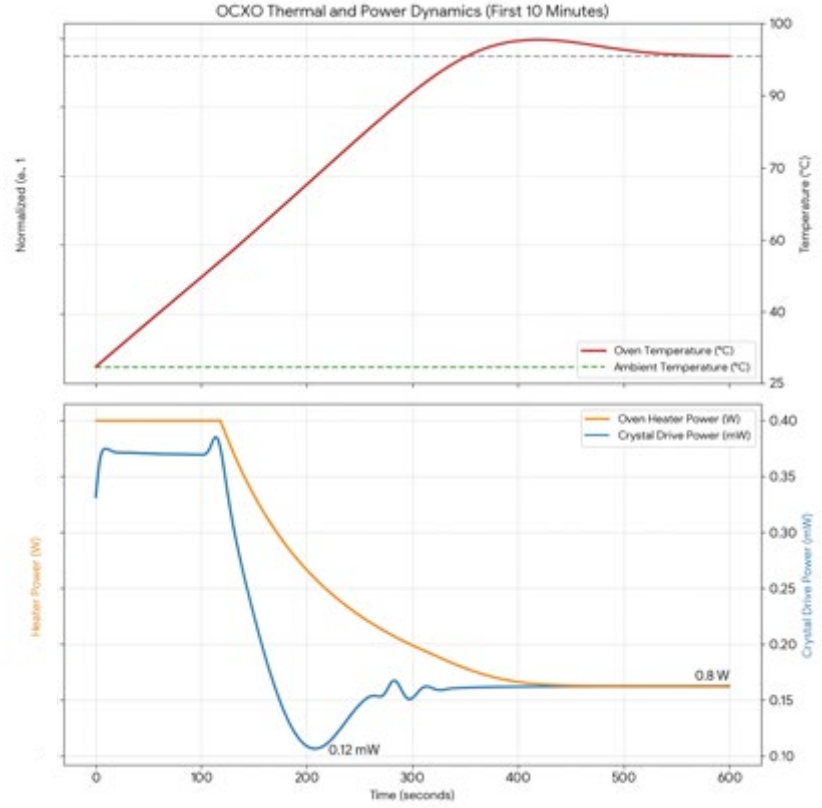




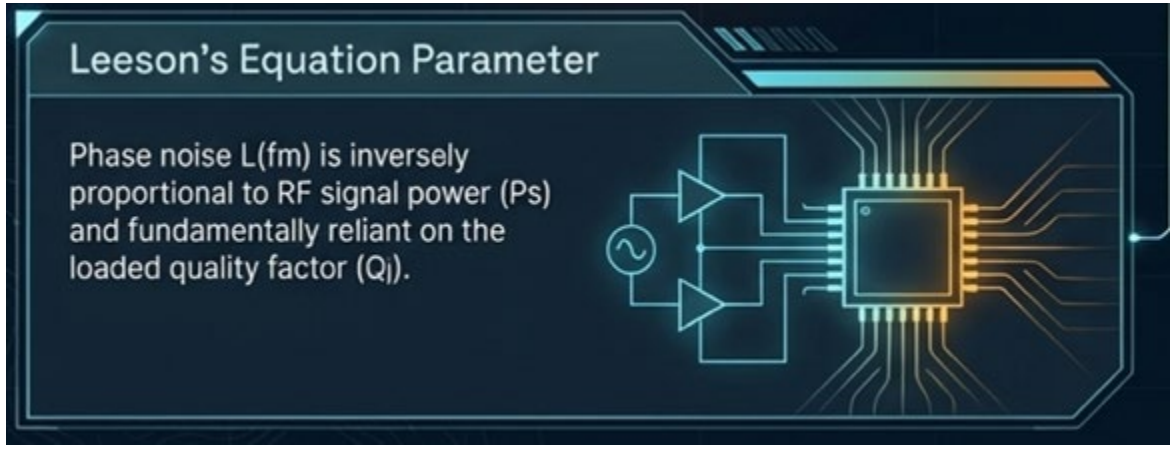
Ref: *John Vig*

Power vs Spectral Purity





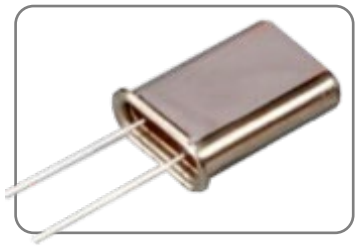
$$\mathscr{L}(f_m) = 10\log_{10}\left[\frac{2FkT}{P_s}\left(1+\left(\frac{f_0}{2Q_l f_m}\right)^2\right)\left(1+\frac{f_c}{|f_m|}\right)\right]$$

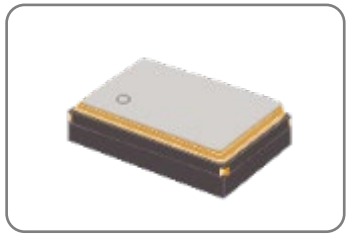


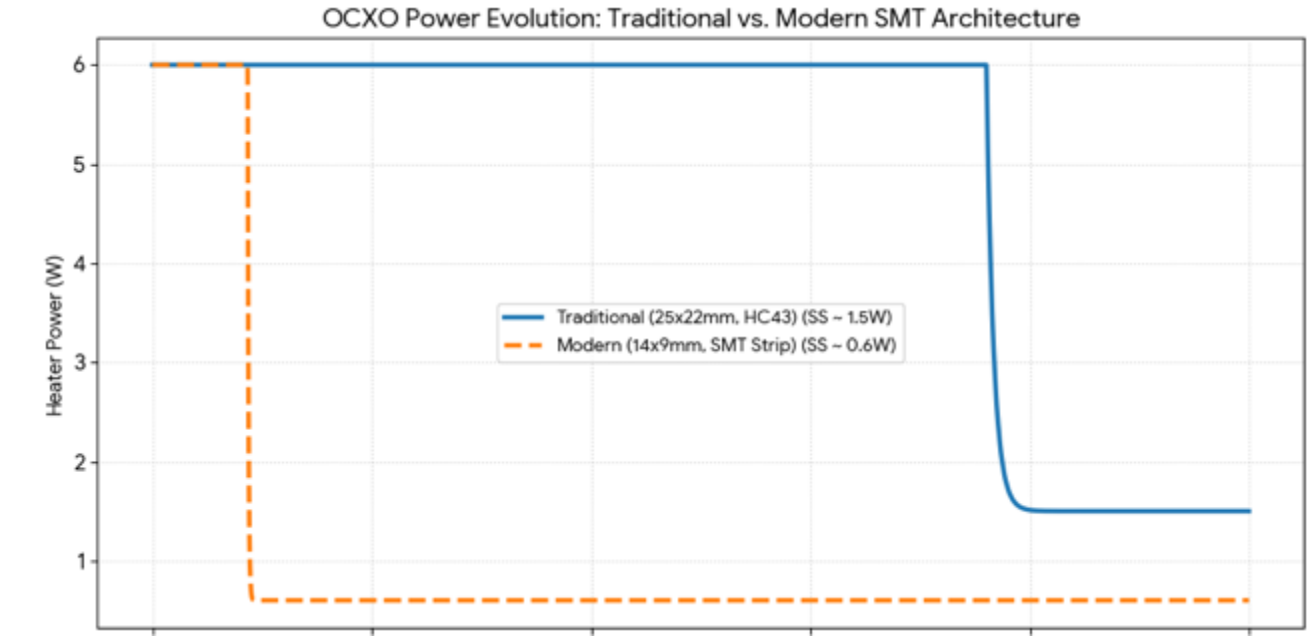
- $\mathbf{L}(f_m)$: Single-sideband phase noise in dBc/Hz at offset f_m.
- f_0: Output frequency.
- f_m: Offset frequency from the carrier.
- Q_l: Loaded quality factor of the resonator.
- F: Noise factor of the active device (amplifier).
- k: Boltzmann's constant (1.38×10^{-23} J/K).
- T: Absolute temperature in Kelvin.
- P_s: Signal power at the amplifier input (often the power through the resonator).
- f_c: Flicker ($1/f$) noise corner frequency. Wikipedia +4

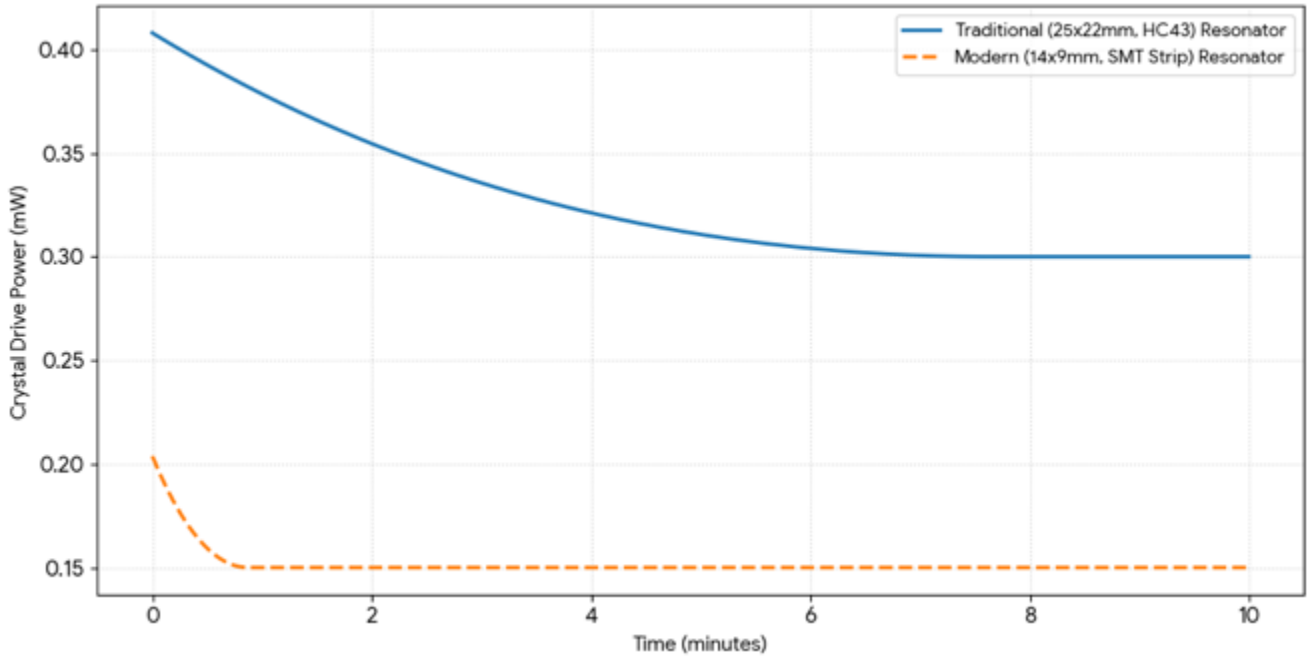
Holder Crystals vs Strip – SC cut

Feature	HC43 crystal	Strip Crystal
OCXO Footprint	550 mm^2	126 mm^2
Thermal Mass (C)	≈40 J/°C	≈5 J/°C
Warm-up Time	≈5 minutes	≈1 minute
Steady State Power	≈1.5 W	≈0.6 W



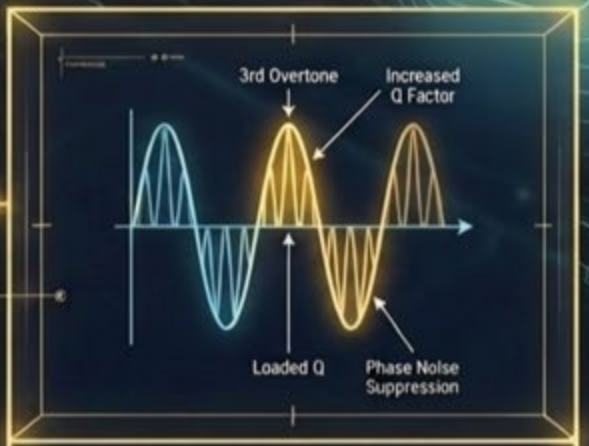






Key design elements to achieve low power

Advanced Low-Power Engineering Techniques



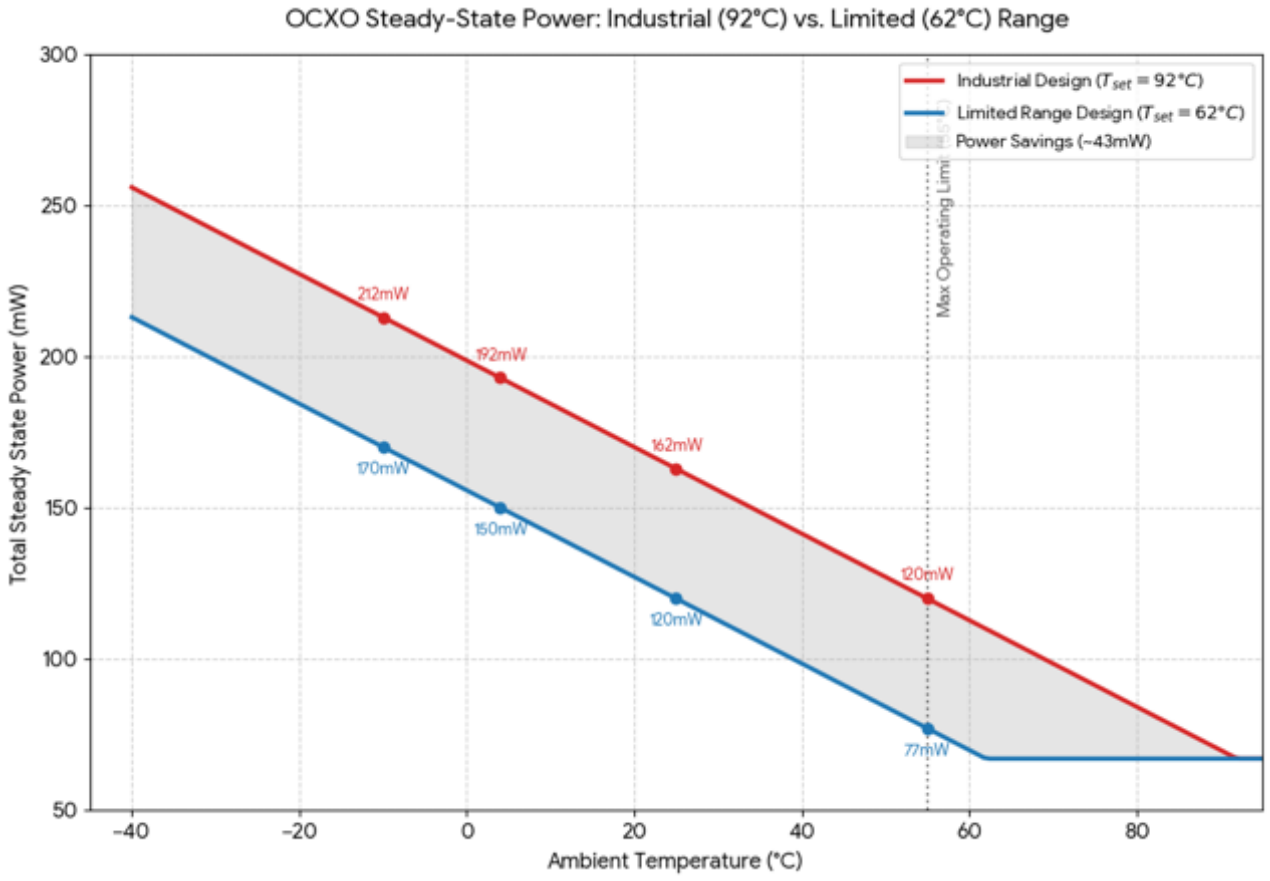
Pillar 3: High-Overtone Operation

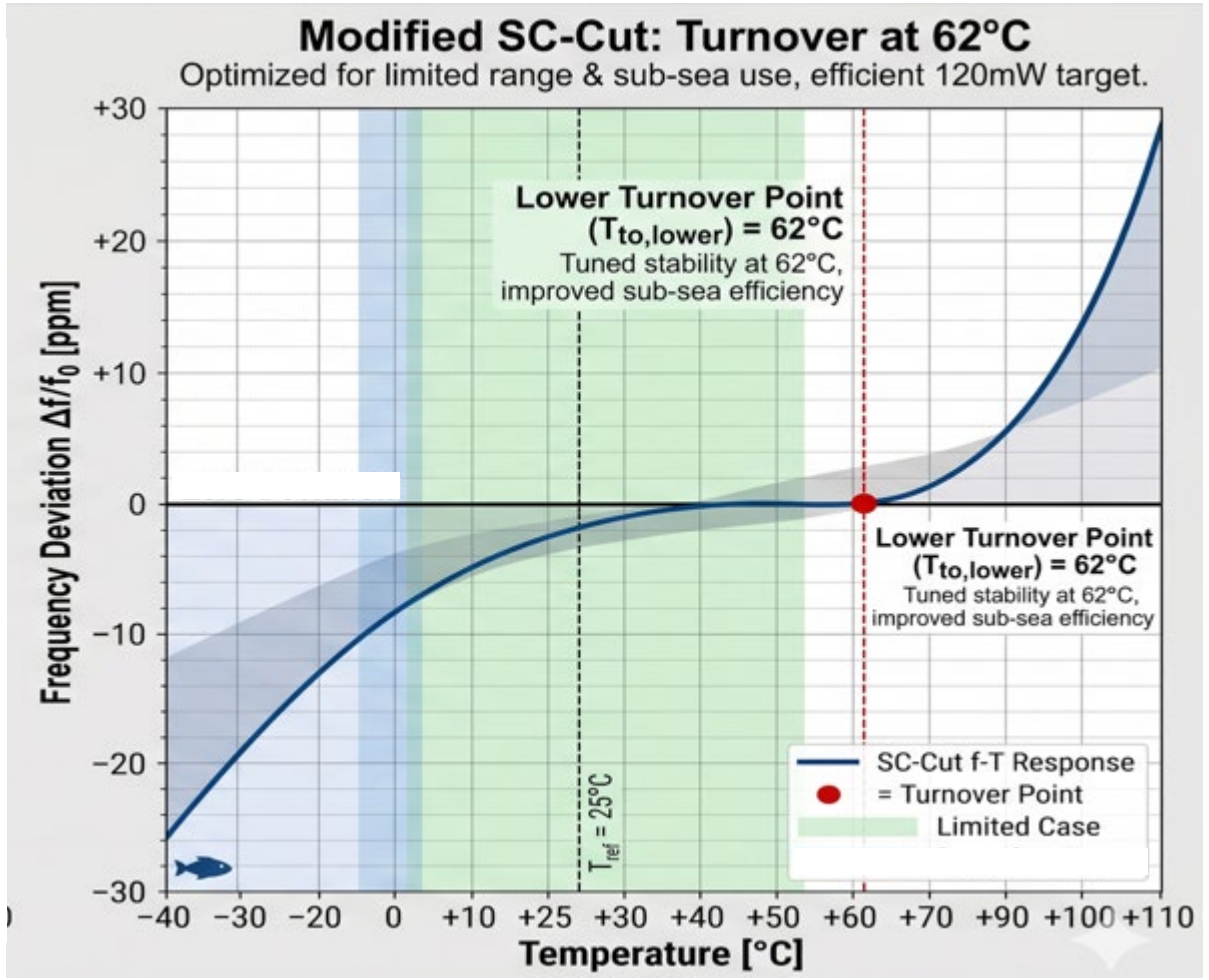
Action: Bypassing Leeson's Penalty.

Running SC-cut crystals at their 3rd or 5th mechanical overtone. This increases the loaded Q factor by 3x to 5x, severely suppressing phase noise to compensate for intentionally low RF drive levels.

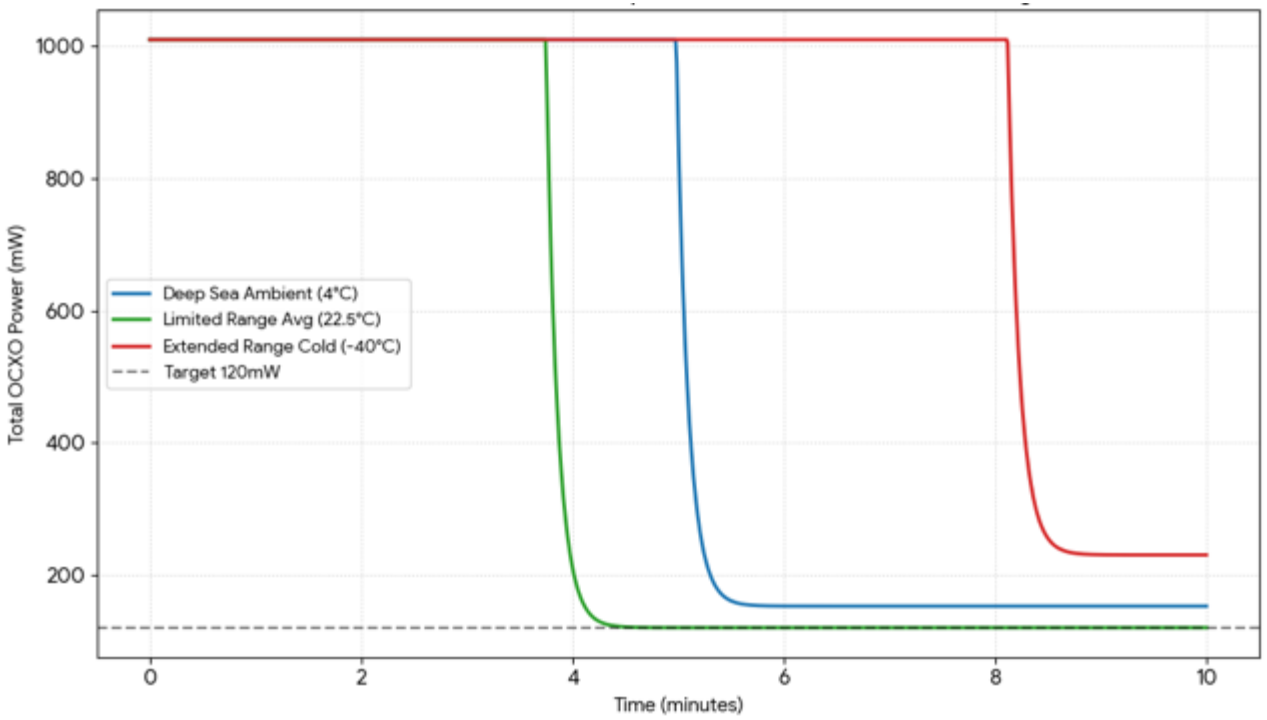
Limiting operating temperature range

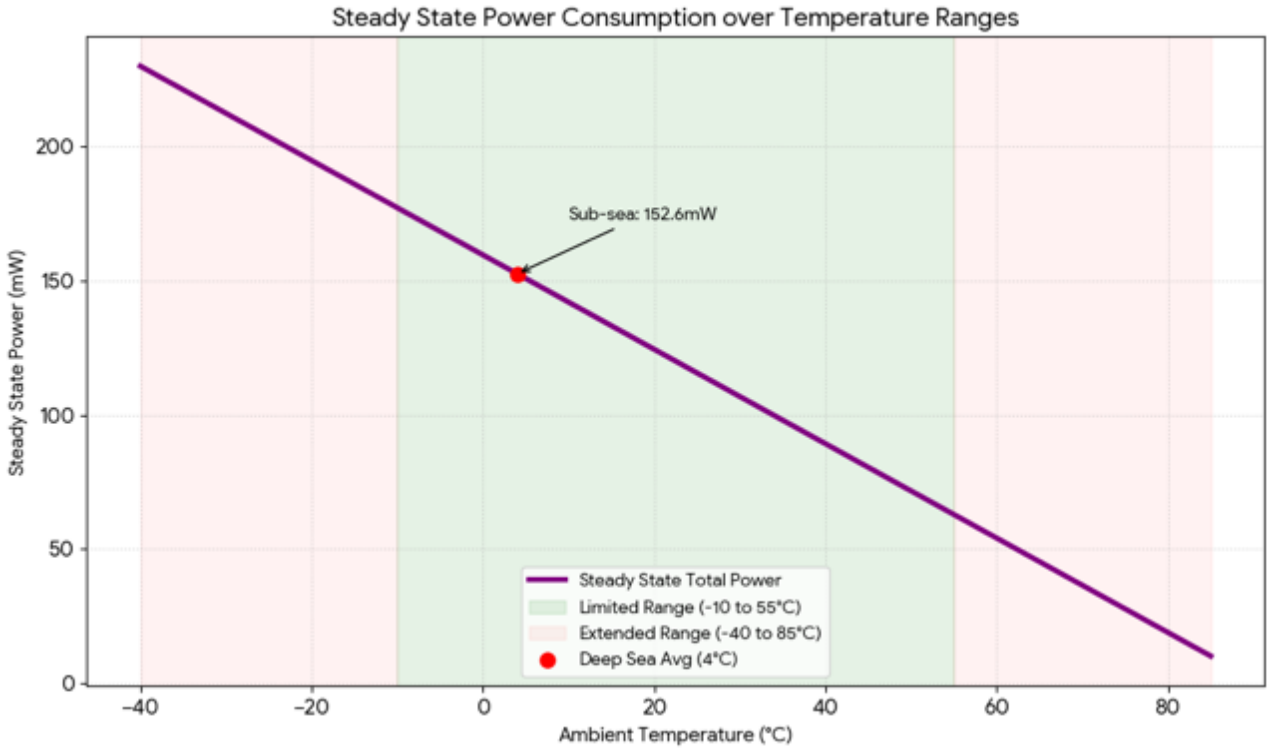
Industrial (-40 to 85) vs application range (-10 to 55)





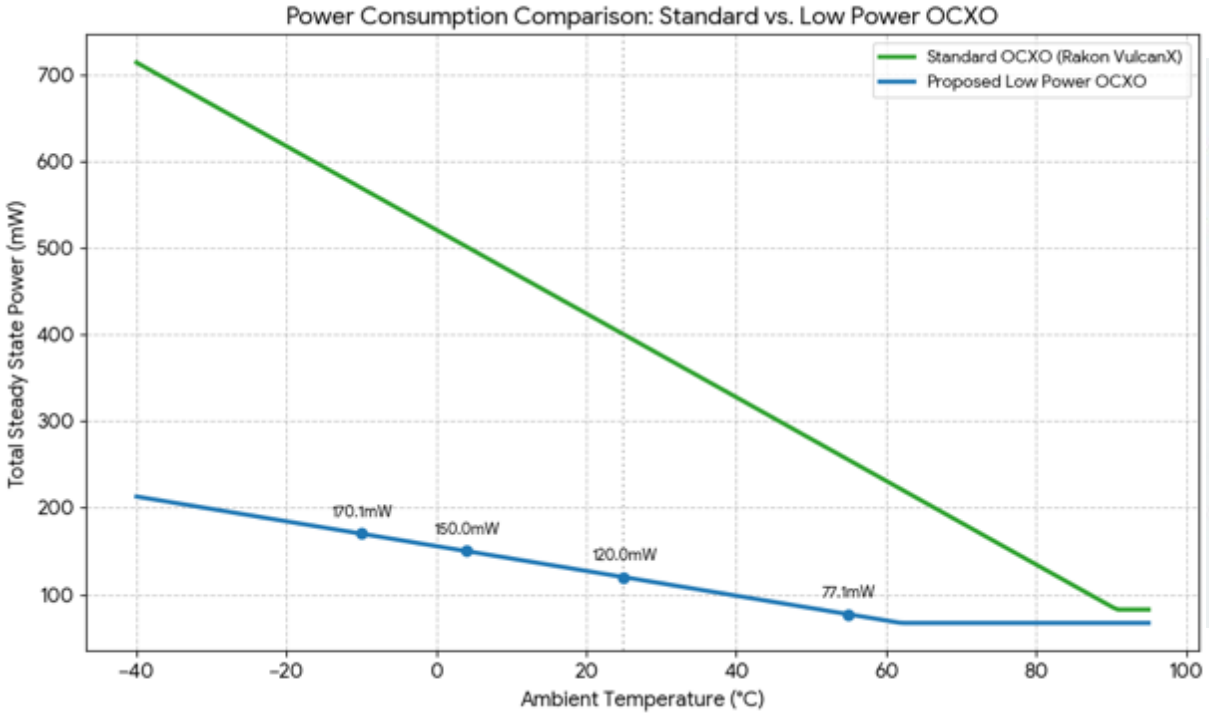
Warm up examples





Managing thermodynamics

Typical SMD OCXOs have higher thermal leakage



P_{steady}

The Target

Steady-state electrical power dissipated by the heater must perfectly equal heat lost to the environment.

$$P_{steady} = \Delta T \times C_{leakage}$$

Delta T (Thermal Gradient)

The difference between internal Oven Temp and external Ambient Temp.

$C_{leakage}$ (Leakage Coefficient)

The rate of thermal energy loss from the system per degree of temperature difference (mW/°C).

Creating Isolated Micro-climate

Leakage for Hermetically Sealed Devices

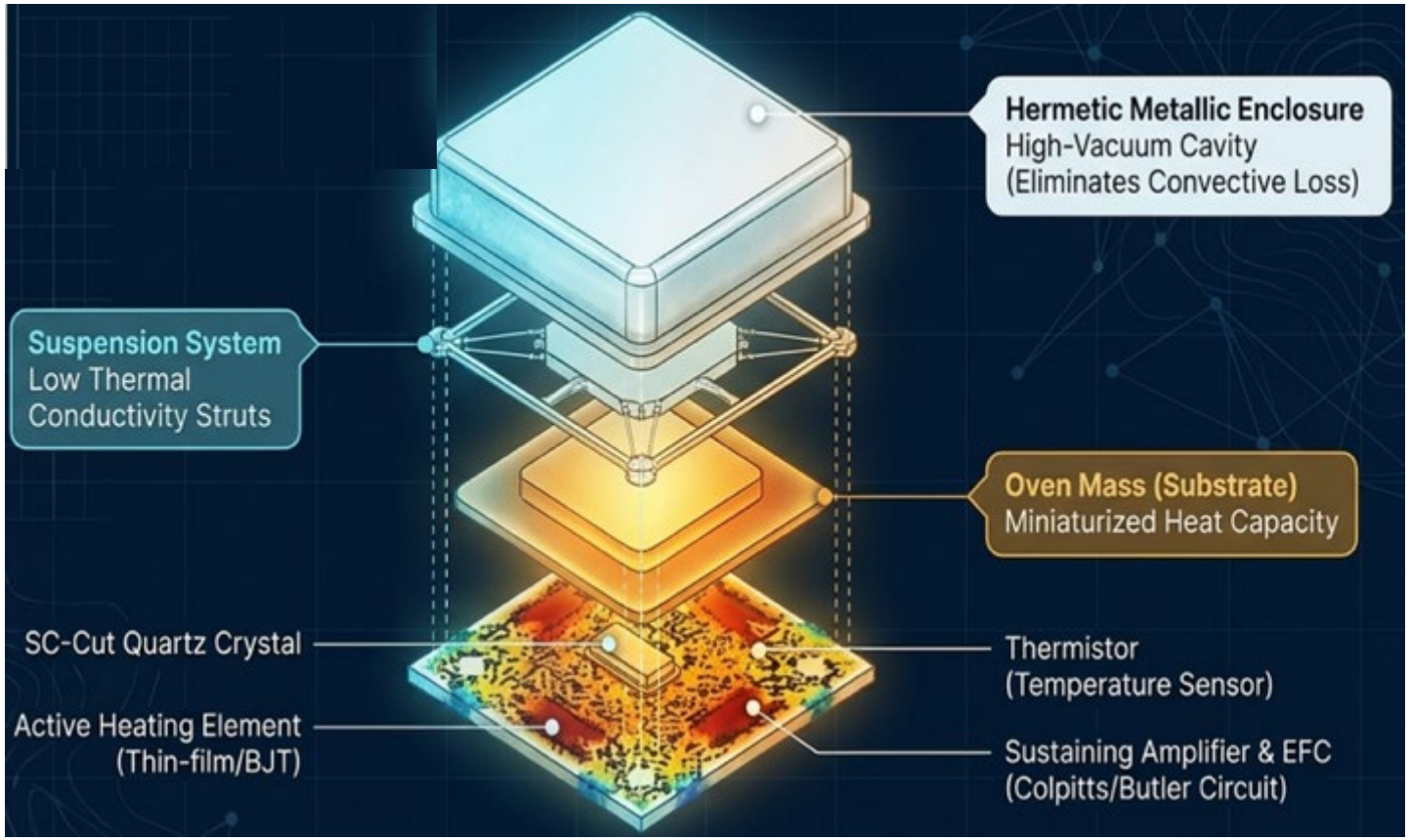
- 3.5-4.5mW/^{o}C

Target specification

- 1.3-1.5mW/^{o}C

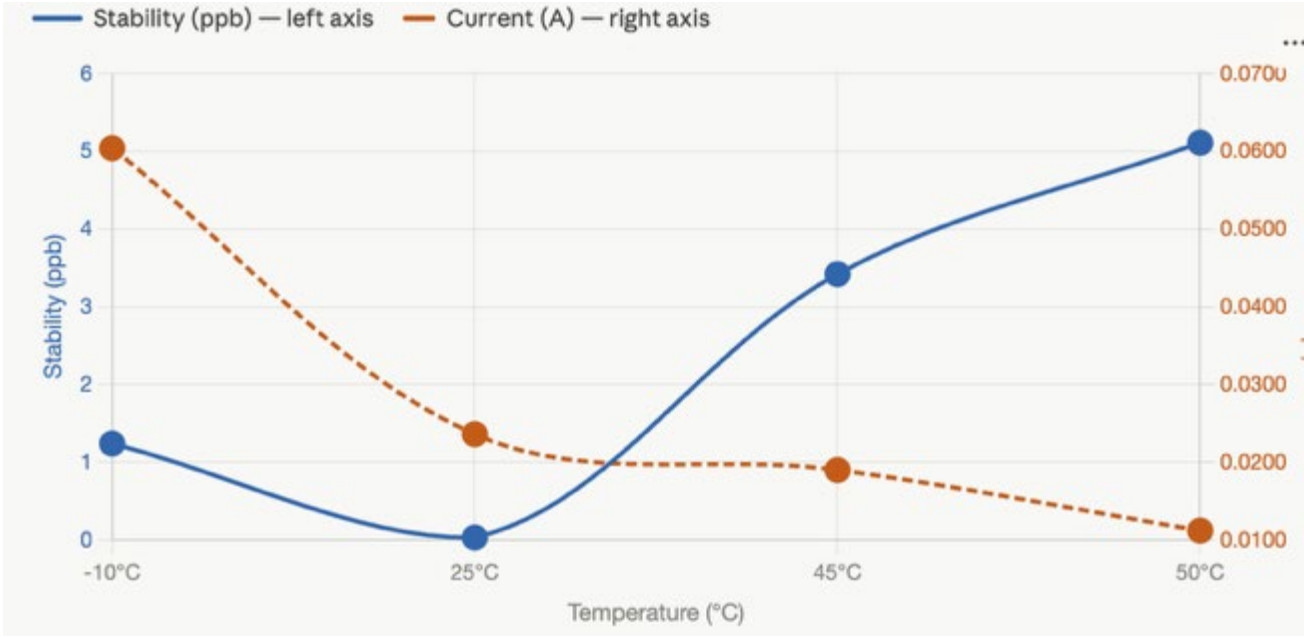
Improving thermal leakage

- Vacuum Encapsulation
- Structural Support Minimisation
- Low-Emissive Coatings
- Low-profile crystals



Measurements on the LP OCXOs

Startup current		262 mA	
Turnover Point	at 60 °C	5V VCC	
Temperature in degrees	Frequency	Stability in ppb	Current(A)
-10	19999959.79	1.24	0.0604
25	19999959.77	0.03	0.0236
45	19999959.83	3.42	0.0190
50	19999959.87	5.11	0.0112



Low Power OCXOs are viable options

	CHIP-SCALE ATOMIC CLOCK (CSAC)
CORE TECHNOLOGY	Coherent Population Trapping
STEADY-STATE POWER	< 120 mW
WARM-UP PROFILE	Fast (< 180s)
STABILITY & AGING	Ultimate (< 9E-10 / month)
IDEAL DEPLOYMENT	Prolonged GPS-denied missions, Undersea OBNs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