New OCXO Contributes to Lower Power Consumption

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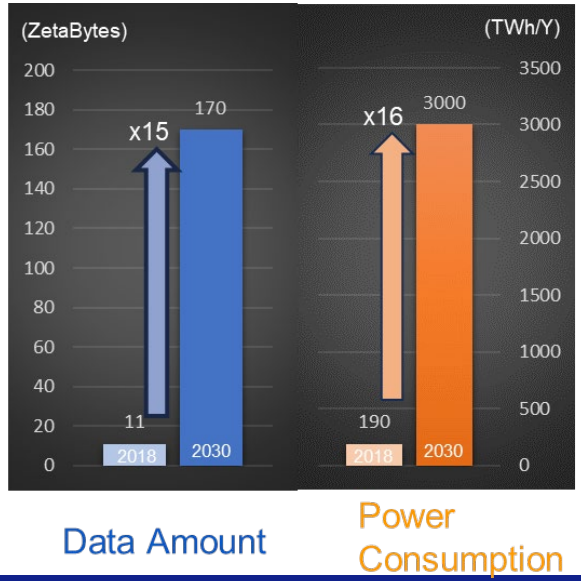
The Need for “Low Power” consumption in networks

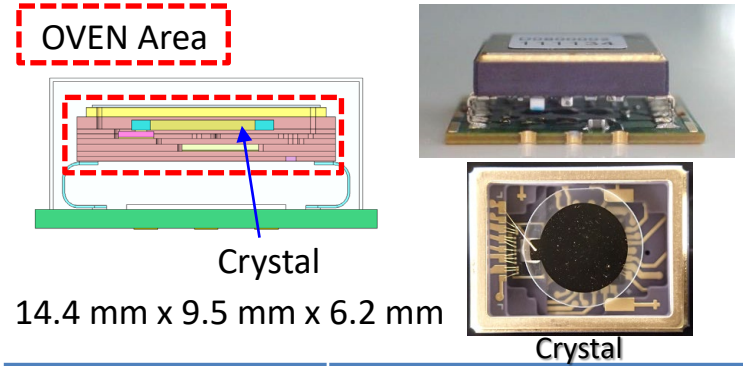
- The expansion of 5G / 6G / AI will increase the demand for High-Stability oscillators.
- The Data traffic and the power consumption of networks will be increased.
- New OCXO contribute to society as point of “Low Power” consumption and “High-Stability”.



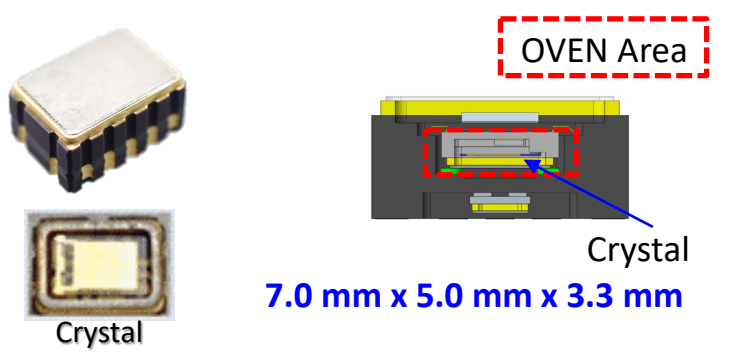
Source : Center for Low Carbon Society Strategy, Japan Science and Technology Agency

New Concept OCXO “Low Power” & “High-Stability”

Conventional OCXO



New Concept OCXO



	Conventional	New Concept	Mark
Power	0.43 W (25 °C)	0.2 W (25 °C)	*-56%*
Freq. vs Temp	± 10 × 10^{-9} (-40 °C to +85 °C) Typ.	± 1 × 10^{-9} (-40 °C to +105 °C) Typ.	*-90% Wide Range*
Holdover	1.5 µs / 8 h	1.5 µs / 8 h	*Same*
Freq. range	10 MHz to 40 MHz	1 MHz to 170 MHz	*Higher Freq.*
Crystal	6mmΦ SC-Cut	Small Rectangle SC-Cut	*-90%*
Product Size	14.4 mm x 9.5 mm x 6.2 mm	7.0 mm x 5.0 mm x 3.3 mm	*-85%*

Challenges for “Low Power” & “High-Stability”

Low Power

Ⅰ） Miniaturization of the OVEN Area
- Miniaturization of the SC-cut Crystal

Ⅱ） Thermal insulated structure
- Reduction of Parts

High-Stability

Ⅰ） High-Precision OVEN control
- Thermal insulated structure
- Not affected by airflow

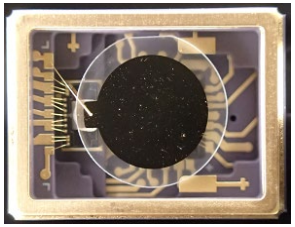
Ⅱ） Use High Q SC-cut Crystal
- SC-cut is more accurate than AT-cut

Ⅲ） Wide temperature range, High frequency

✔ Miniaturization of the SC-cut Crystal
✔ Thermal insulated structure
✔ High-Precision OVEN control

Miniaturization of the SC-cut Crystal

Important characteristic of a crystal is the Q value
- ✓ Q value is related to Phase Noise
- ✓ Q value needs to be high

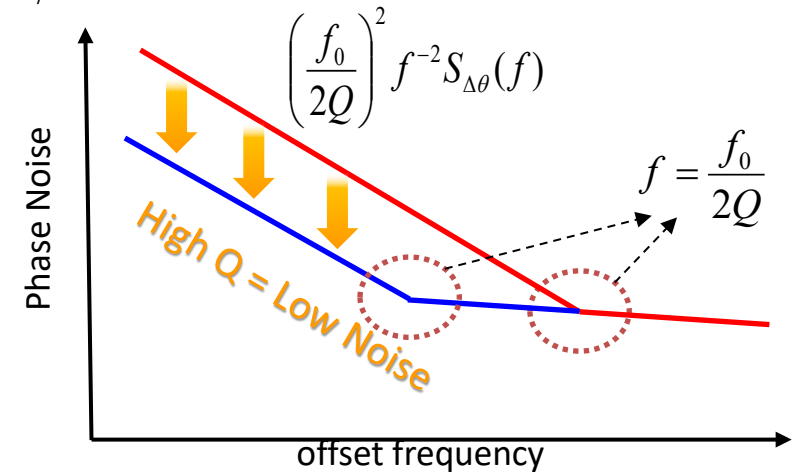


❑ Conventional SC-cut (6mmΦ)
- Circular shape :
  Reduce the effect of reflection
- High-Q Value :
  Convex shape and 3rd O/T oscillation

❑ New OCXO's SC-cut Challenges
- Miniaturization :
  To achieve low power consumption
- Phase noise :
  Deterioration due to miniaturization

Phase Noise (Leeson's model)

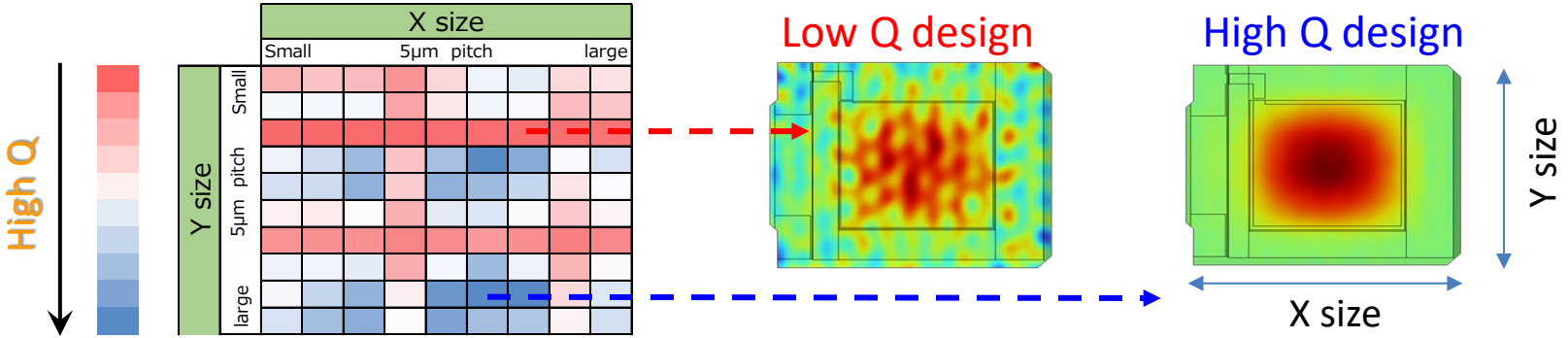
$$S_\phi(f) = \left\{ \left(\frac{f_0}{2Q} \right)^2 f^{-2} + 1 \right\} S_{\Delta\theta}(f)$$



Miniaturization of the SC-cut Crystal

Achieved a High Q value, equivalent to conventional OCXO, with a small SC cut.

Q value simulation using the finite element method(FEM)



Using simulation, we achieved the same Q value as Conventional OCXO

	Conventional	New Concept	Mark
Crystal Size	6mmΦ	Small Rectangle	***-90%***
Q value AVG.	296,845 (40MHz)	293,743 (30MHz)	***Same***

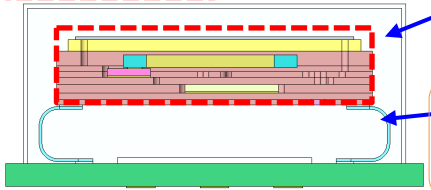
Thermal Insulated structure

Achieved low power consumption through highly insulated structure design

- Efficient oven control through hermetic structure around the oven and use of low-insulation materials
- Double-sealed structure minimizes the impact of outside air-condition

Conventional structures have insufficient insulation

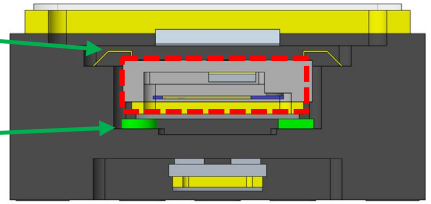
OVEN Area



	Air condition	
Atmosphere		Vacuum
Non-Hermetic seal		Hermetic seal

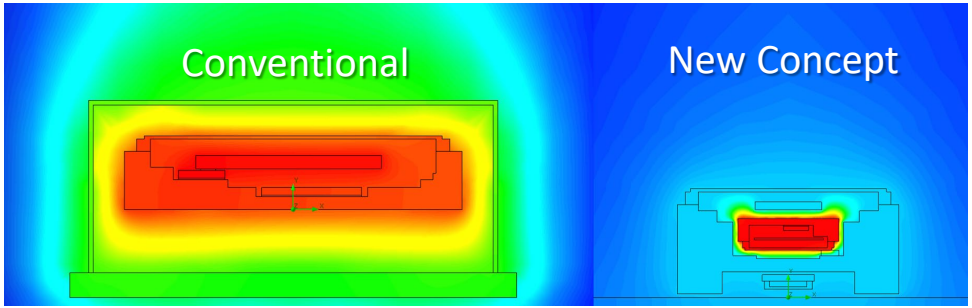
	Insulation parts	
42alloy		Adhesive
14.6 W/(m・K)		< 0.5 W / (m・K)
High thermal conductivity		Low thermal conductivity

OVEN Area



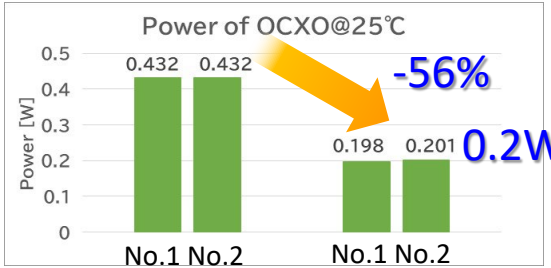
Double sealed structure

Double-layered PKG is less susceptible to airflow



The heat of the oven is confined to the minimum necessary area.

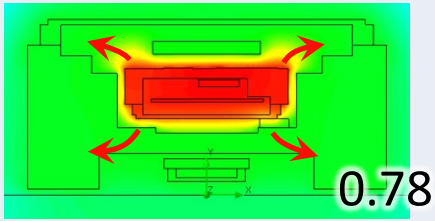
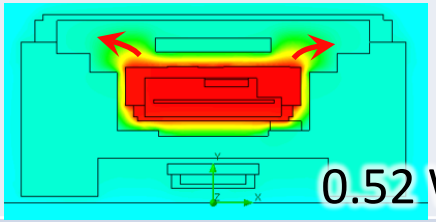
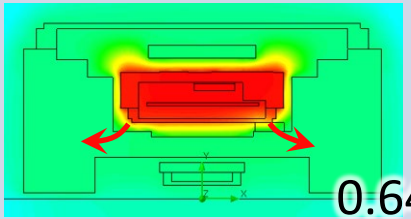
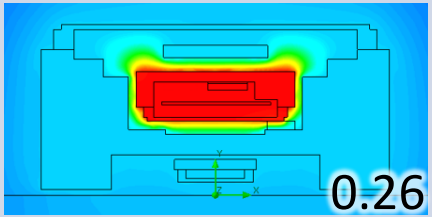
Actual Power measurement



Thermal Insulated structure

The higher the insulation around the oven, the lower the power consumption

Heat Transfer Analysis Simulation

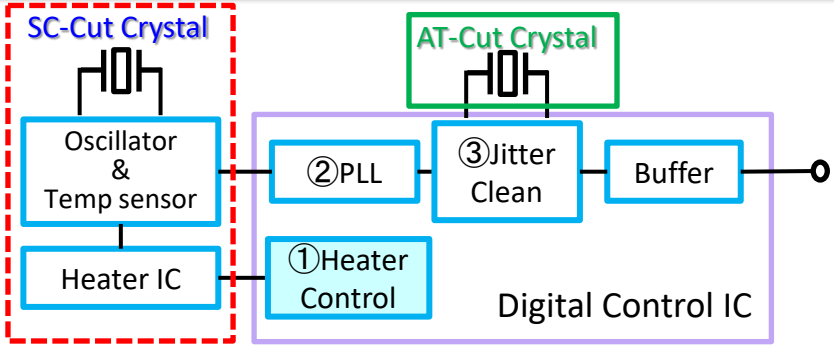
Power required by heater at -40 ºC		Insulated Adhesive (Thermal Conductivity)	
		3.0 W / (m･K)	< 0.5 W / (m･K)
Air condition	Atmosphere	(1)  0.78 W	(3)  0.52 W
	Vacuum	(2)  0.64 W	(4)  0.26 W

(1) Heat dissipation from the adhesive and the top of the Inner PKG
(2) Heat dissipation from the adhesive
(3) Heat dissipation from the top of the Inner PKG
(4) Almost all Heat can be trapped in the Inner PKG→ Low Power consumption

High-Precision OVEN control

Features of the circuit side in improving characteristics

1) The oven control is digital PI control, which reduces the Crystal temperature error and improves the temperature characteristics



In-house IC : Digitally control the oven
Integrate PLL circuit

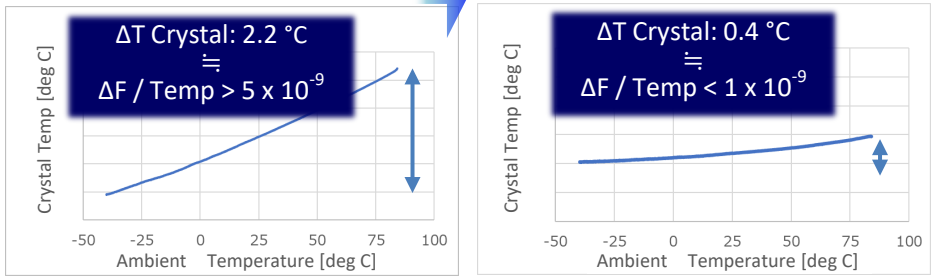
❑ Challenge

・Conventional analog proportional control could not provide detailed temperature control, and the temperature error of the crystal occurred, and the temperature characteristics were about ±5 x 10^{-9} to ±10 x 10^{-9}

① Heater Control

Analog circuit
Proportional Control

Digital Control IC
Proportional-Integral Control

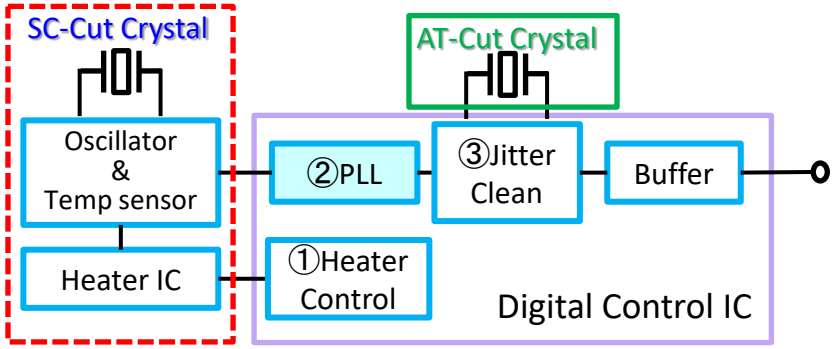


Small crystal temperature change against ambient temperature, excellent frequency temperature characteristics are achieved

Achieving Higher Frequencies

Features of the circuit side in improving characteristics

2) Built-in PLL circuit enables operation up to a maximum frequency of 170 MHz

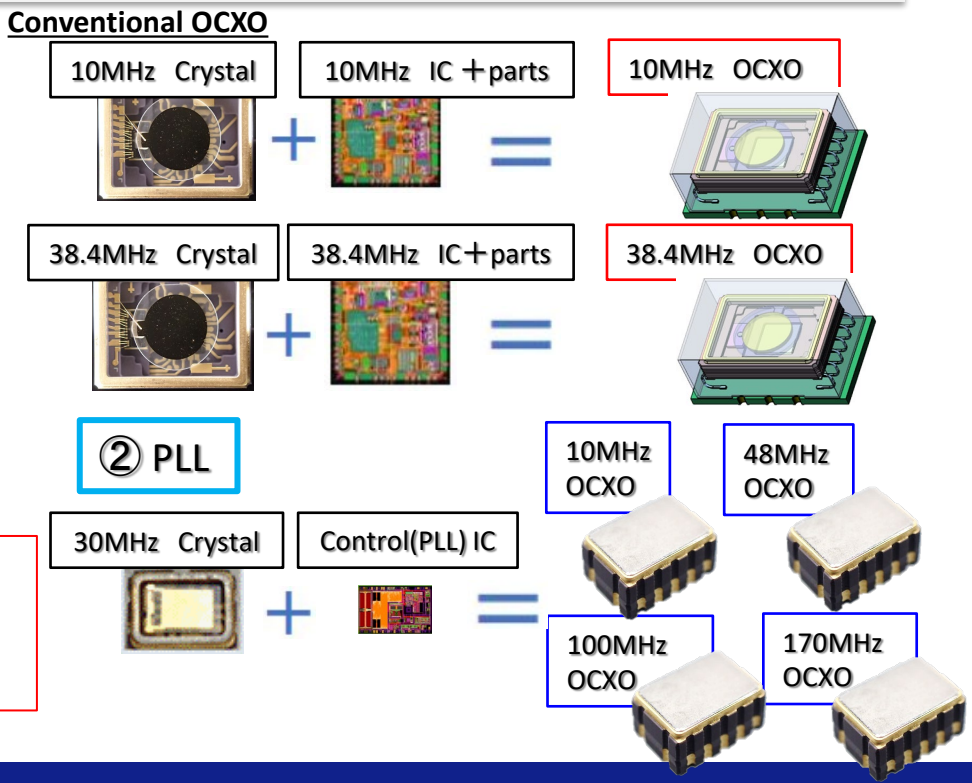


In-house IC : Digitally control the oven
Integrate PLL circuit

❑ Challenge

・In the past, as a result of prioritizing high accuracy, dedicated crystals and dedicated ICs were individually designed for each frequency

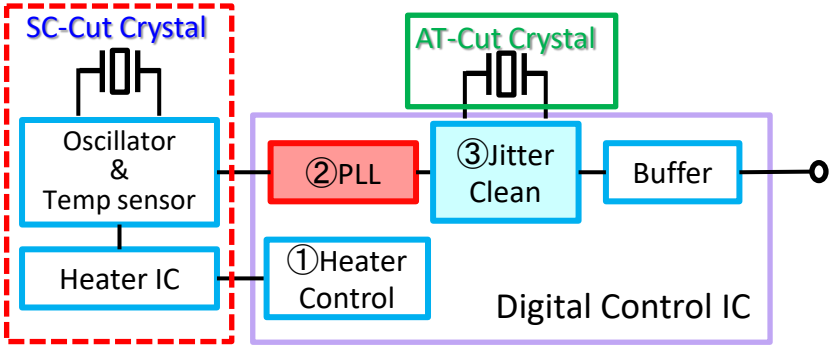
・Supports multiple frequencies



Improving Phase Noise

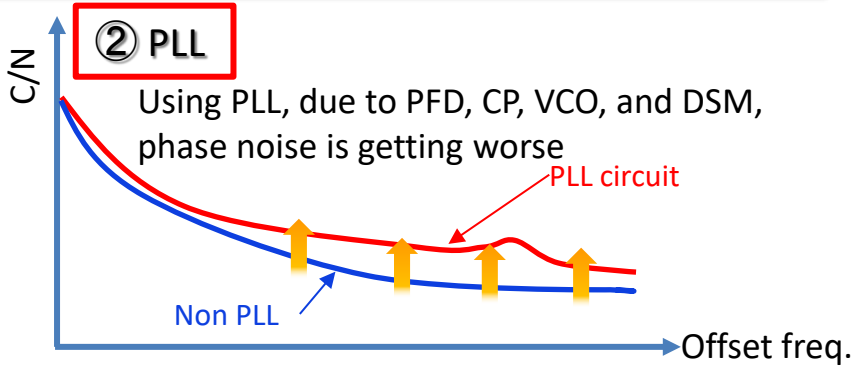
Features of the circuit side in improving characteristics

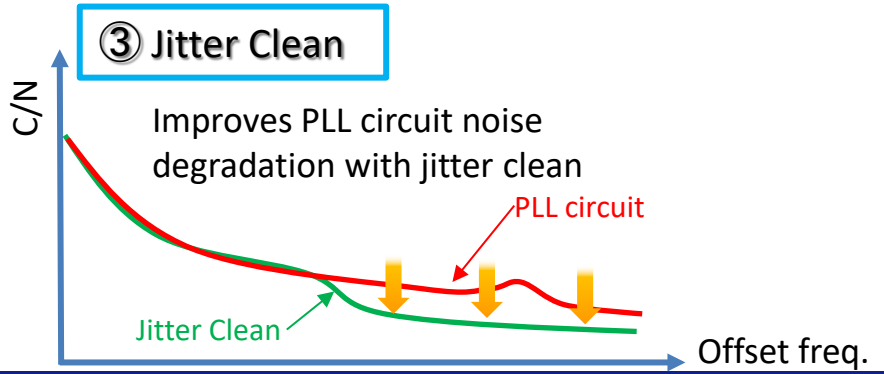
3) Improve floor noise that degradation with PLL by using jitter cleaner



In-house IC : Digitally control the oven

Integrate PLL circuit





❑ Challenge

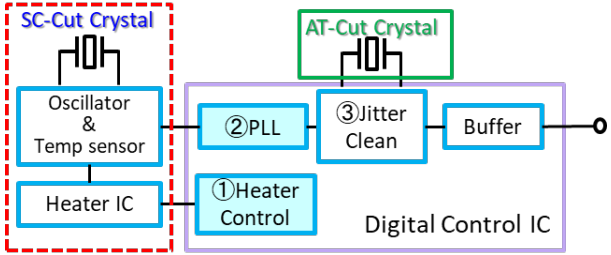
- Nearby carrier frequency noise can be reduced by using a High Q crystal
- Using PLL, degrades the floor noise of phase noise.

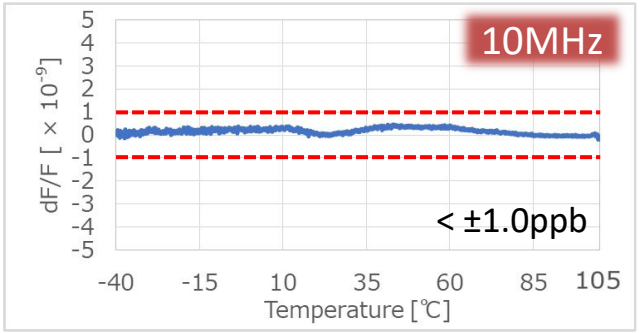
- **Results of Evaluation**

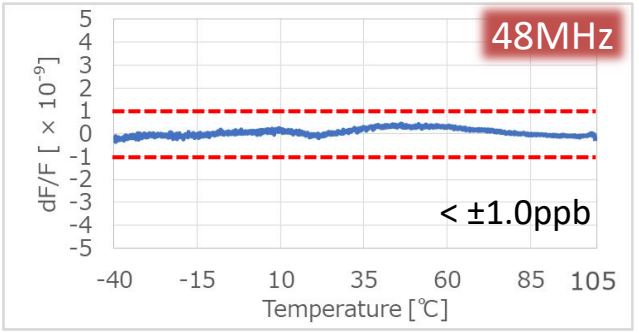
(under development)

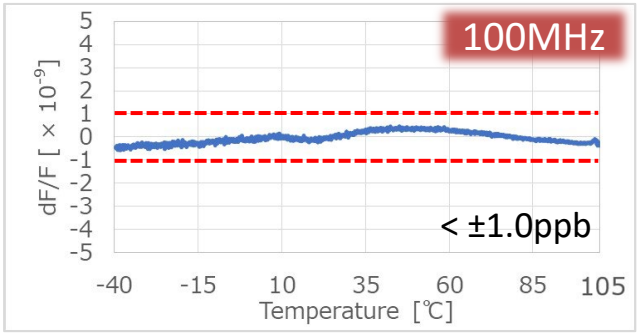
Static Temperature Characteristics

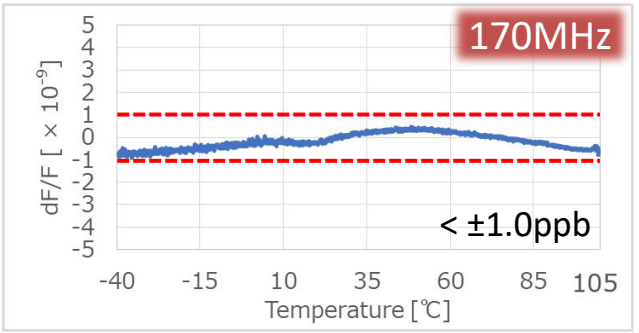
- ✓ High-Precision Oven control achieved ΔF_temp ±1 x 10^{-9}
- ✓ Changing the frequency in the PLL settings does not change the temperature characteristics





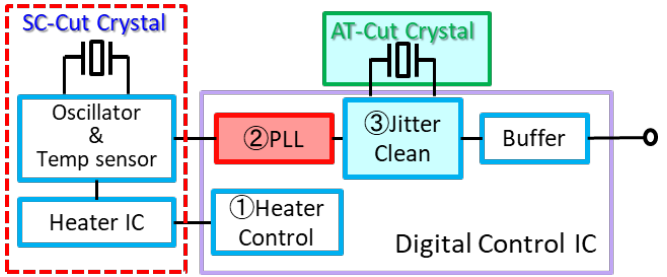




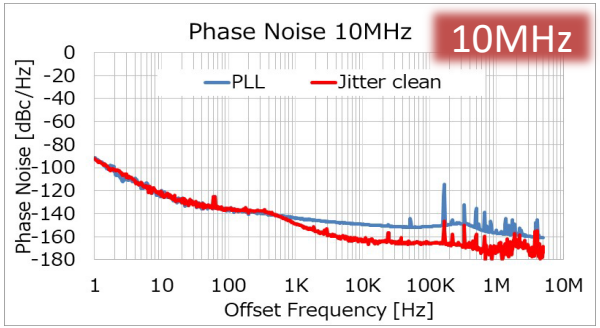


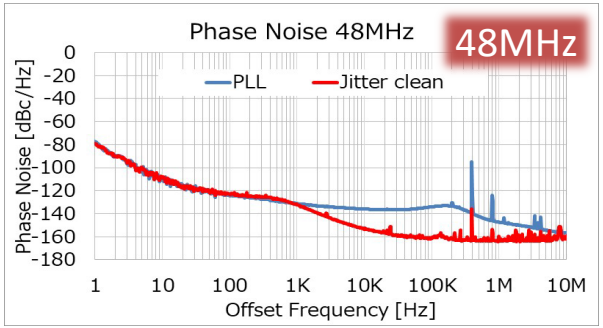
Phase Noise with Jitter Clean

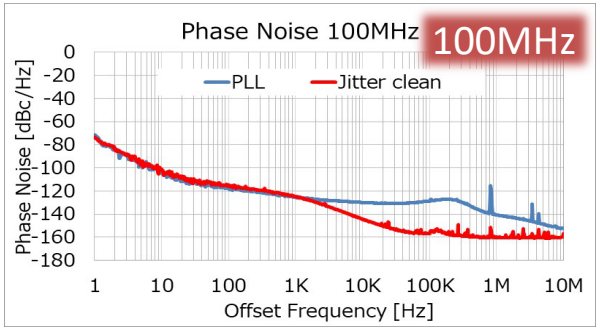
- ✓ Jitter Clean reduces floor noise
- ✓ Achieved -160dBc/Hz regardless of frequency

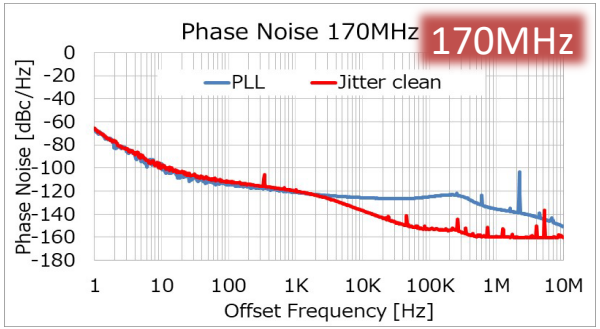


The Phase Noise level worse as the frequency increases.
Using the Jitter cleaner improves floor noise to around -160dBc/Hz.





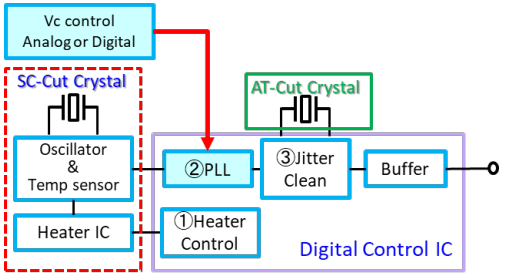




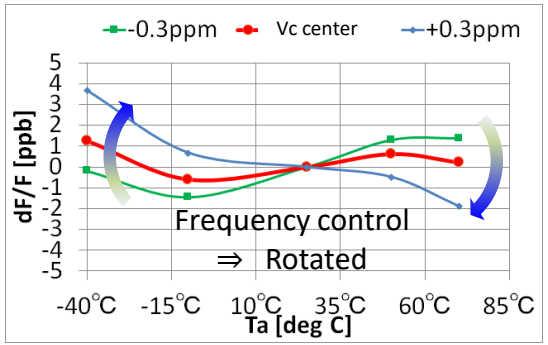
Effect of Digital Frequency control (fine-tuning)

✓ Voltage control (Vc) (Frequency Variable) : Even if Vc is adjusted, the temperature characteristic does not rotate because of the digital control inside the IC.

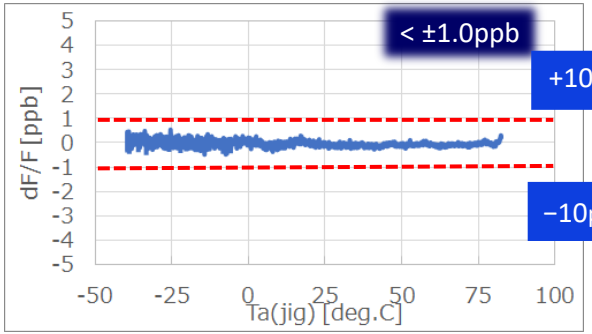
❑ Digital frequency control in the PLL :
- There is no frequency effect by analog circuits,
- Frequency can be adjusted while maintaining temperature characteristics.



Conventional OCXO



New OCXO

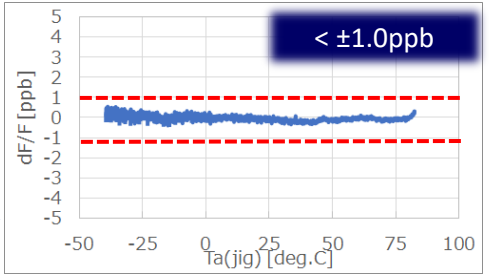


Temperature characteristics

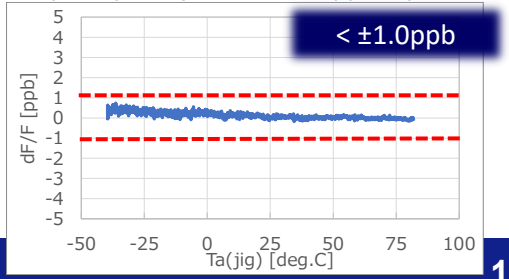
+10ppm

−10ppm

Frequency is adjusted to +10ppm by Vc

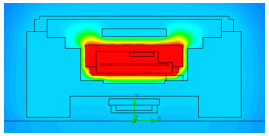


Frequency is adjusted to +10ppm by Vc



Dynamic Temperature Characteristics

✓ Same temperature characteristics even if the slope speed is changed



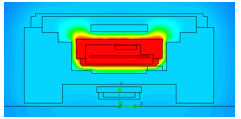
Thermal Insulated structure

Slope Speed

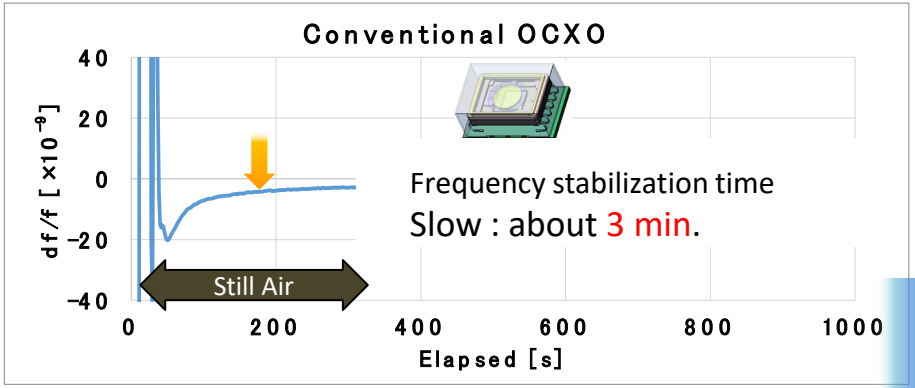
	1 °C/min	4 °C/min	10 °C/min
Frequency temperature characteristics	< ±1.0ppb	< ±1.0ppb	< ±1.0ppb
Frequency temperature Slope	< ±0.1ppb/ °C	< ±0.1ppb/ °C	< ±0.1ppb/ °C

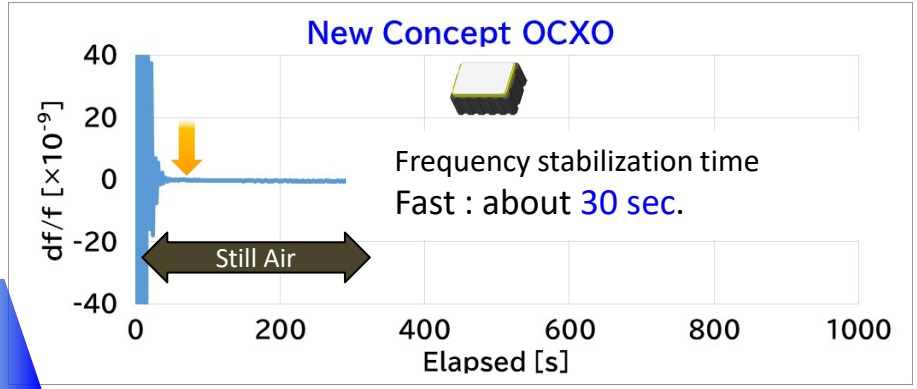
Start up time (Frequency Stabilization Time)

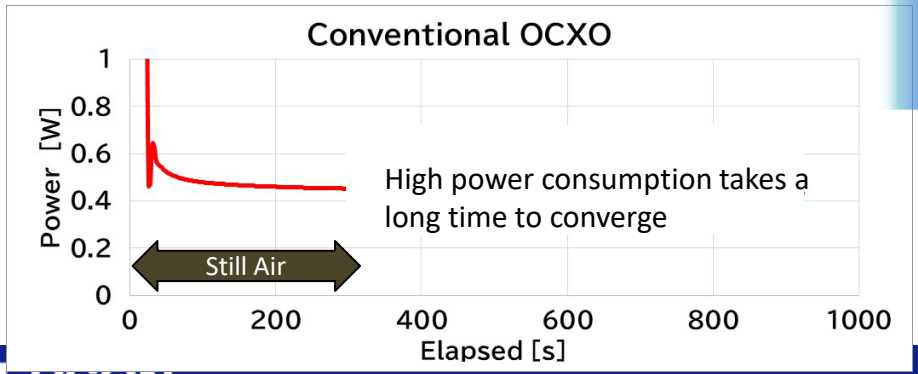
- ✓ Low power consumption enables fast frequency stabilization time
- ✓ Warm-up time < 30 sec typ.

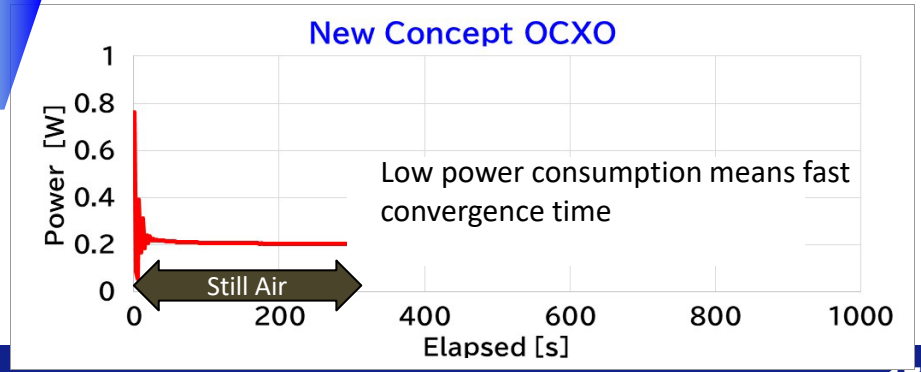


Low Power consumption



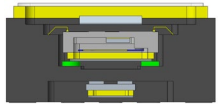




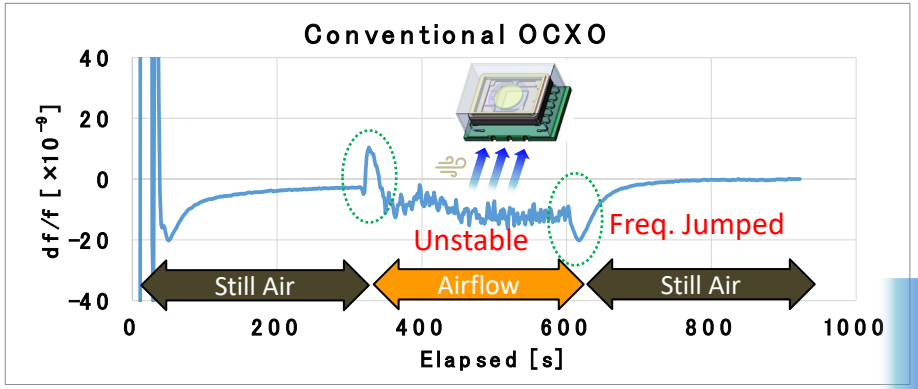


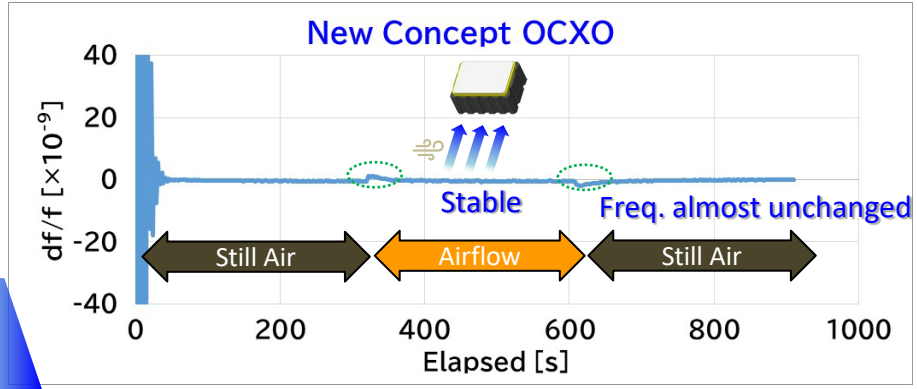
Airflow Performance

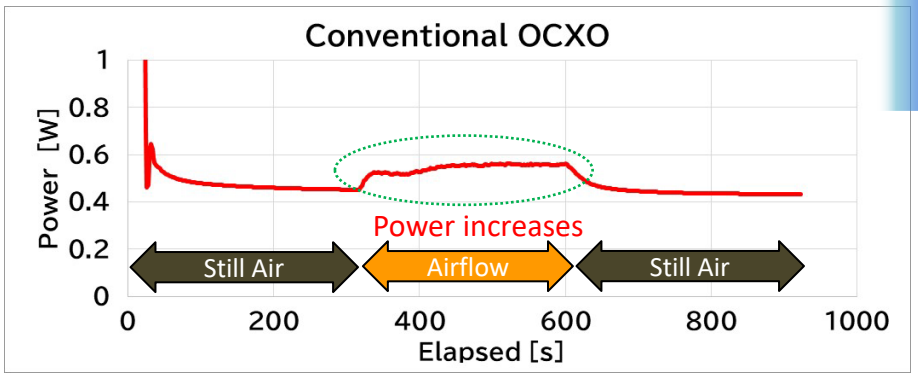
✓ Improves Airflow performance & Achieves low power consumption

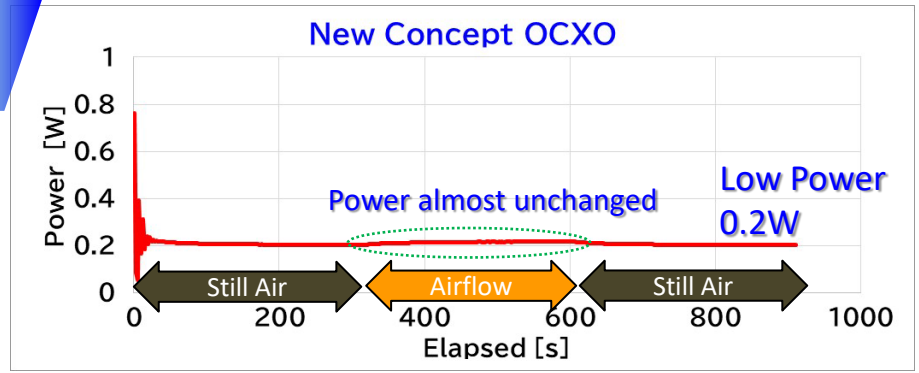


Double sealed structure



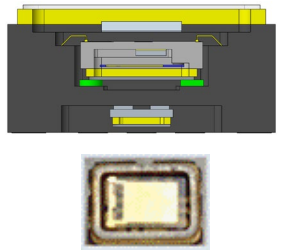


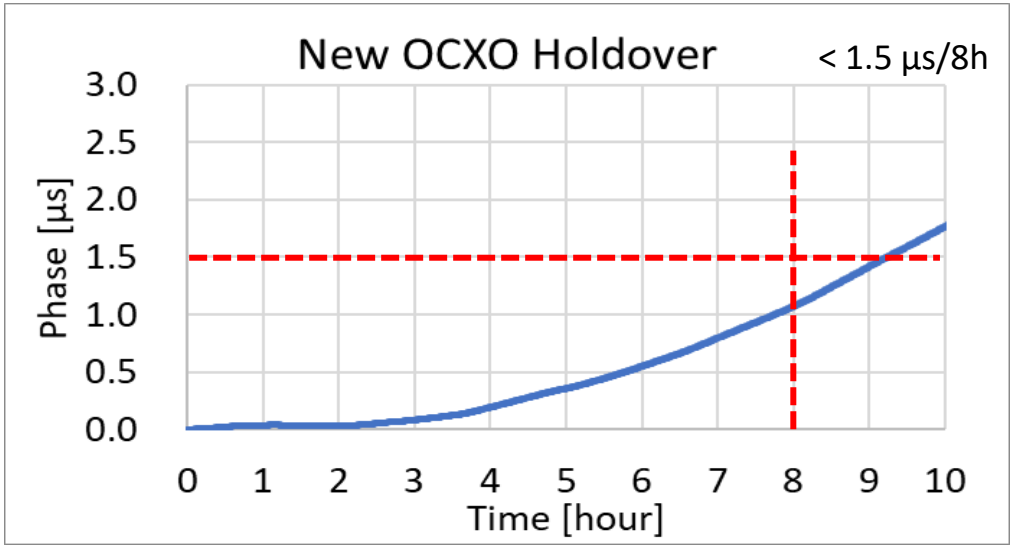




Holdover Characteristics

✓ Achieved 1.5 µs/8h Hold over characteristics, equivalent to conventional OCXO



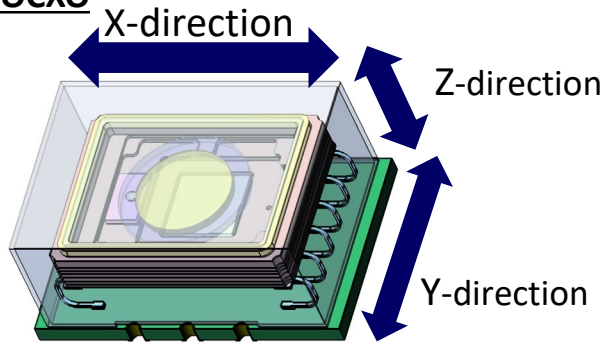


❑ Measurement condition:
- 25 °C constant
- Transition to Holdover after 10 days after startup
- High-Q

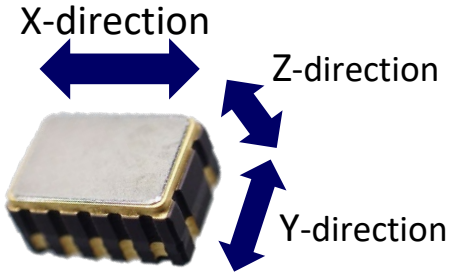
G-sensitivity

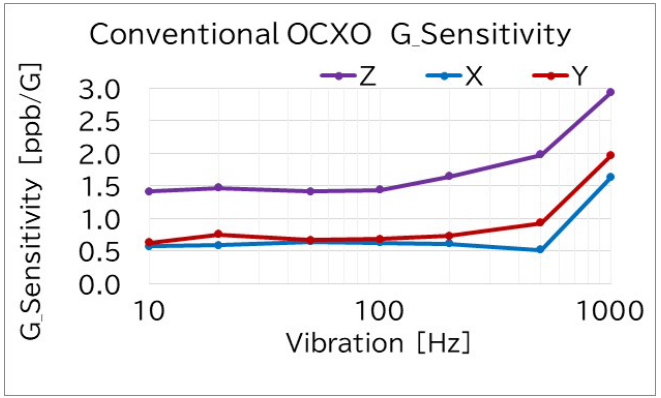
✓ Improved G-sensitivity in all directions, because crystal size became small
In particular, the Z-direction (vertical) has been greatly improved

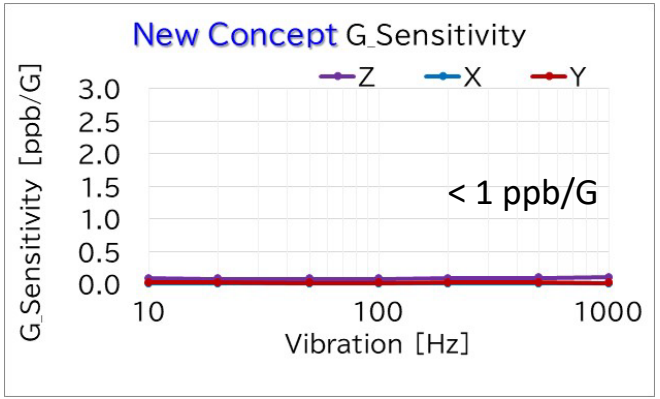
Conventional OCXO



New OCXO







Summary

- ✓ We achieved Low Power consumption OCXO through Miniaturization of the OVEN Area and Thermal insulated structure
  - -- Power : 0.2 W
  - -- Startup time : 30 second
- ✓ We achieved High-Stability OCXO with performance equal to or better than conventional type through High-Precision OVEN control and SC-cut Crystal , PLL circuit
  - -- Freq. vs Temp : < ± 1 × 10^{-9} Typ. (-40 ° C to +105 ° C)
  - -- Freq. range : 1 MHz to 170 MHz
  - -- Airflow : Improved
  - -- Hold Over : < 1.5 µs / 8 hours
  - -- G-sensitivity : < 1 ppb/G

EPSON