# New state of the art of thermal sensitivity with Space Ultra Stable Quartz Crystal Oscillator


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## INTRODUCTION

Over the past years research went into improving the thermal sensitivity of RAKON's space quartz crystal ultra stable oscillator (USO). RAKON France (CEPE until 1998, C-MAC from 1998 to 2007, RAKON since early 2007) has been working with CNES (the French Space Agency) to continuously improve performances of Ultra-Stable OCXO (USO) : OUS-NG [1-2]. Its frequency sensitivity has a strong influence on final performances of DORIS system (Doppler Orbitography and Radio-positioning Integrated by Satellite, CNES system) which uses RAKON's USO. The DORIS system is used in satellites such as 'TOPEX-POSEIDON', 'JASON', 'SPOT', 'CRYOSAT', 'PLEIADES', and 'ALTIKA'. Significant effort has been put into additional improvements, mostly with regards to the thermal performances and preparation of the new generation of a miniature USO. The quartz crystal oscillator has to be studied by taking a multi-physics approach. A part of this work has been conducted in a PhD thesis with Femto-ST Institute and with support from CNES [3-4].

## OUS-NG THERMAL PERFORMANCES

To increase the resolution under the centimetre in the DORIS system, the main required improvement is to reduce the frequency thermal sensitivity of the USO. On Figure 1, we present the statistical distribution of the relative frequency thermal sensitivity for the latest manufactured NG-USOs. We can see a repartition with mean value at $7.10^{-13}$/°C and standard deviation of $5.10^{-13}$/°C. But for the new DORIS requirement, the frequency thermal sensitivity mean value must be reduced to $2.10^{-13}$/°C and with a standard deviation of $3.10^{-14}$/°C, which is state of the art and leading in terms of space USO performance (see table 1, the competition figures is from [5] from J Norton published in 1996 ). At the beginning of the study, the usual tools used for the simulation (mechanical simulation in one hand and thermal simulation in the other hand) seemed to not be sufficient in estimating and explaining the total frequency drift versus temperature. So a full 3D thermo-mechanical simulation of the USO was conducted, with introduction of the piezo-electric phenomena of the quartz crystal resonator [3-4-6-7-8-9].

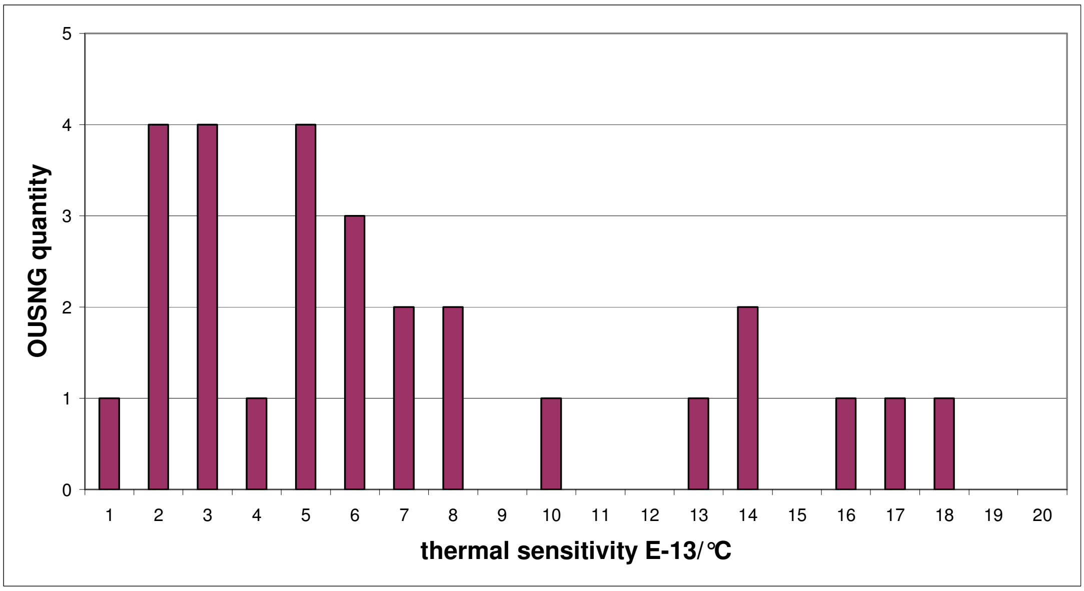


**Figure 1 OUSNG relative frequency thermal sensitivity statistical distribution**

**Table 1 Specifications or performances of USO**

| SPACE USO / Parametres | | Rakon | Competition | |
|---|---|---|---|---|
| | | OUSNG PHARAO | Type 142 [10] | Type 150 [10] |
| Spec/Perf | | Perf | Perf | Perf |
| output frequency (MHz) | | 5 | 5 | 10 |
| ageing(/24h) | | 1.25E-12 | 8.10E-11 | 2.60E-12 |
| Allan standard deviation | 1s | 6.00E-14 | 8.38E-14 | 2.70E-13 |
| | 10s | 7.00E-14 | 3.74E-14 | 1.60E-13 |
| | 100s | 8.00E-14 | 6.09E-14 | 1.50E-13 |
| thermal sensitivity (/°C) | | 7.61E-13 | 4.30E-13 | 8.00E-14 |
| weight (kg) | | 1.05 | 1.91 | 0.2 |
| Consumption (W) | | 1.66 | 1.48 | 0.34 |
| volume (L) | | 0.7 | 1.74 | 0.14 |

## A MULTI-PHYSICS APPROACH

The USO is a complex assembly of mechanical and electronic parts. Moreover, Rakon's USO is a Double Oven Controlled Crystal Oscillator (D-OCXO) and the quartz crystal is very sensitive to temperature. So an important part of the USO is dedicated to building very stable thermal operating conditions for the quartz crystal. Figure 4 shows a possible approach to studying the USO. Each part has to be studied as an independent item at the first step; then they have to be optimized with mutual interactions between 2 items at the second step, then the three items studied together to reach the ultimate performance.

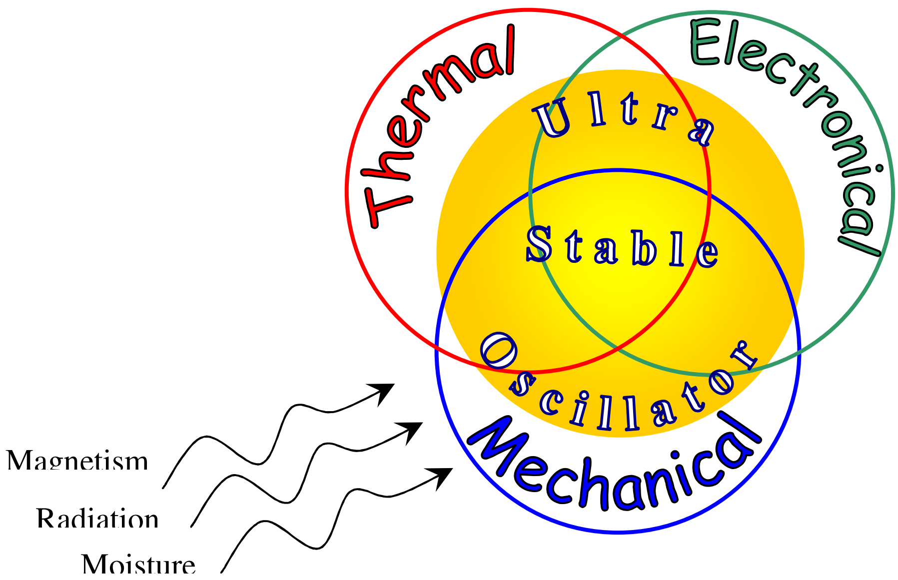


**Figure 2 A way to see the different parts of an USO**

## THERMAL EFFECT IN THE RAKON USO

The requirement of thermal controlled precision is leading to a thermal structure with a Dewar vessel. Then a mechanical structure has been designed to provide resistance to launch conditions and to meet space requirements. Once combined, those two structures conduct to impose a temperature distribution on the resonator illustrated by figure 5. The resonator used in Rakon's USO is a quartz crystal with a QAS structure [10].

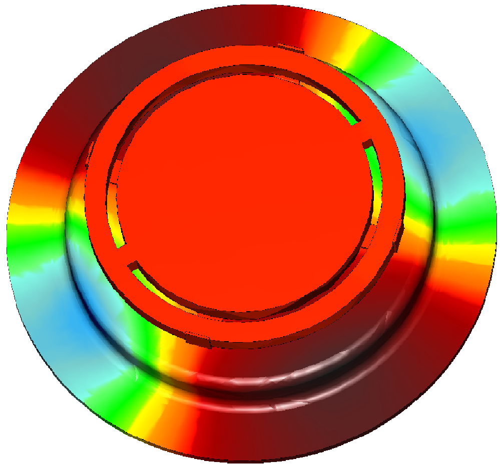

**Figure 3 The distribution temperature on the resonator structure due to the USO thermal structure, the resonator is a QAS mounted in a HC40 package (from blue to red, difference of temperature is within less than 1.10$^{-3}$°C)**

## NEW TOOL TO STUDY THE USO

To better evaluate the mechanical impact of the structure on the crystal resonator, a simple thermal study is not precise enough. A new tool using a well known quartz theory [7-8-9] has been developed. To verify and validate its precision, a comparison has been made based on experimental results of Ratajski [11] and usage of this tool. Figure 6 shows related results. The graphs show that there is a good correlation between experimentation and simulation.

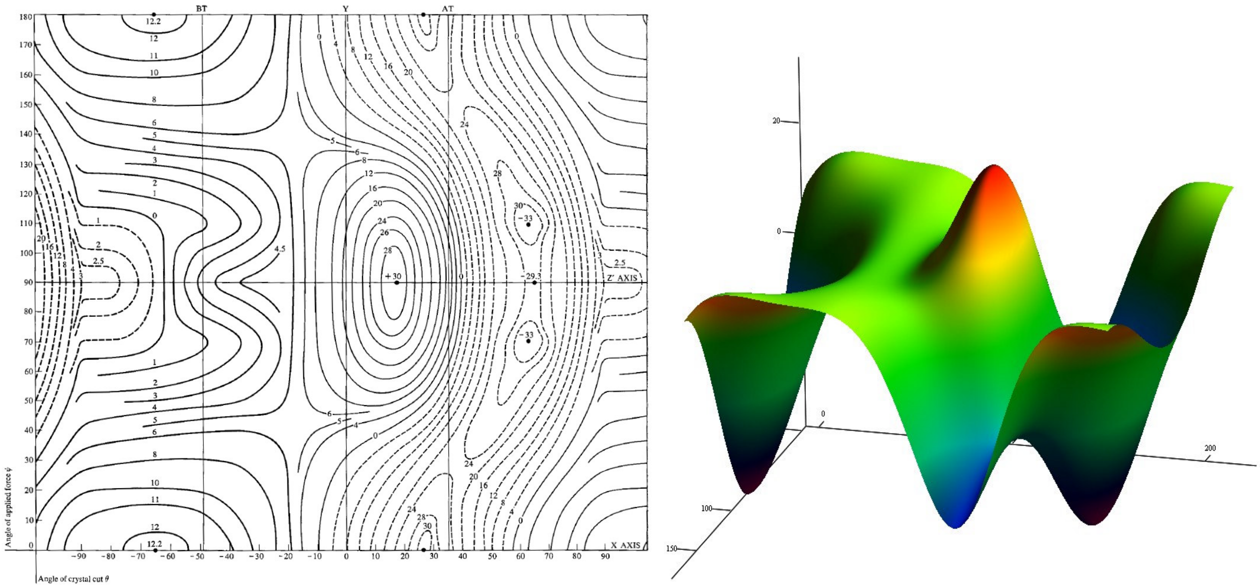


**Figure 4 The comparison of experimental and simulation determination of the Ratajski Force-Frequency coefficient (in 10$^{-15}$msN$^{-1}$). The left figure is from Ratajski publication [11], the right is obtained by simulation with the new tool**

## RESULTS

Work carried out using the different approaches on the possible interactions of the various parts of the USO, was conducted to make significant progress in understanding one restrictive phenomenon. A USO modification has been done to minimize this phenomenon which (with regard to thermal sensitivity), has enabled the best performance achievable from a USO: $5.10^{-14}$/°C on Rakon's USO. Figure 7 provides evidence of these results.

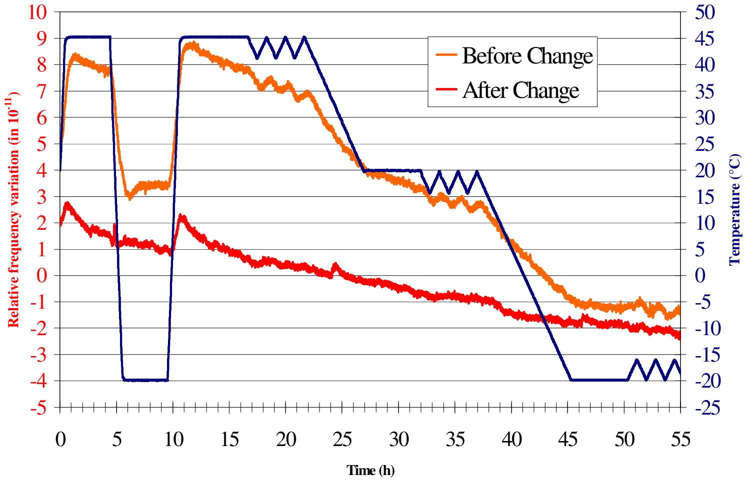


**Figure 5 Frequency drift during DORIS thermal vacuum test of the Rakon USO**

## CONCLUSION

The results obtained from this study show a significant improvement in the comprehension of one restrictive multi-physics phenomenon. The new performance of $5.10^{-14}$/°C achieved here is the best performance ever obtained by any space USO worldwide. This is a great development prior to Rakon beginning the next stage of downsizing the USO structure for future programs.

## REFERENCES


[1] V Candelier, J Lamboley, G Marotel, P Canzian and P Poulain, "Recent progress in ultra stable oscillators for space on board and ground applications", *15th EFTF pp 325-331*, 2001

[2] V Candelier, P Canzian, J Lamboley, M Brunet, G Santarelli, "Space Qualified 5 MHz Ultra Stable Oscillators", *Joint Meeting EFTF - IEEE IFCS pp 575-582,* 2003

[3] L Schneller, S Galliou, B Dulmet, P Canzian, V Candelier and G Cibiel, "Effect of quartz crystal thermal structure on its performance in ultra stable oscillators", *EFTF 8pp*, 2008

[4] L Schneller, "Contribution à l'élaboration d'un Oscillateur Ultra Stable Spatial Miniature : Etude et réduction de la sensibilité thermique", *Thèse 181pp, Université de Franche-Comté*, 2009

[5] J Norton, J Cloeren and P Sulzer, "Brief history of the development of ultra precise oscillators for ground and space application", *IEEE 50th IFCS pp 47-57*, 1996

[6] S Galliou, "Thermal Behaviour Simulation of Quartz Resonators in an Oven Environment*", IEEE UFFC, vol 42 no 5 pp 832-839*, 1995

[7] F Deyzac, "Finite elements method modelling of accelerometric and barometric sensitivity of quartz resonators", *7th EFTF pp 291-295,* 1993

[8] J Kosinski, R Pastore, X Yang, "Stress induced frequency shifts in Langasite thickness-mode resonators", *IEEE IFCS pp 716-722*, 2003

[9] J Baumhauer and H Tiersten, "Nonlinear electroelastic equations for small fields superposed on a bias", *J. Acoust. Soc. Am., vol 54 no 4 pp1017-1034*, 1973

[10] J Lamboley, V Candelier and F Courtade, "Ultra-stable 5 MHz Xtal resonator with very low G-sensitivity and noise", *18th EFTF pp 359-364,* 2004

[11] J Ratajski, "Force-Frequency coefficient of singly rotated vibrating quartz crystals", *IBM Journal, pp 92-99, 1968*