nanOSTAR-SP Compact OCXO for New Space applications

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INTRODUCTION

To meet the growing demand of integrated oscillators for constellations in LEO orbit, AR Electronique (ARE) has designed a new family of COTS OCXO, nanOSTAR-SP. This family has been developed in order to guarantee low mass, low volume, reduced power consumption, improved RF performances, together with attractive market price. Thanks to short production and delivery time, ARE solution can also address scientific / experimental missions.

This family of products will be the new state of the art OCXO for “New Space” applications.

Derived from the full defense/airborne qualified OCXO nanOSTAR-S, this “New space” segment version has been designed to ensure good immunity to dose (TID). The sensitivity to heavy ions and protons are being evaluated with the French Space Agency (CNES).
The reliability of the product has been qualified according to drastic defense/airborne criteria, guaranteeing excellent robustness linked to the launch constraints.

PRODUCT DESCRIPTION

The nanOSTAR oscillator is based on an oven controlled oscillator structure (OCXO) to guarantee the best compromise between frequency stability and Allan deviation. The crystal resonator developed and manufactured by ARE, is oven controlled as finely as possible to present the best performance in temperature.

The oscillator is packaged in a metal case ensuring a hermeticity in the order of few 10^{-9} atm.cm^{3}.s^{-1}, as well as a low humidity content (< 5,000ppm). The reunification of these parameters greatly improves the reliability of the assembly.
The oscillator is packaged in a volume of less than 5cm^{3} (20x20x10mm), with a mass of less than 10 grams (Fig. **1**).
The power consumption is in the range of 700mW at +25°C. The warm-up power is limited to 1.5W. The power supply of the nanOSTAR-SP is between +3.3V and +5V.
This low consumption associated with high electrical performance, low mass and low volume allows this new product family to stand out from our competitors

To meet the requirements of "New space" customers, ARE is able to deliver oscillators in 4 to 7 months (depending on the frequency requested by the customer).

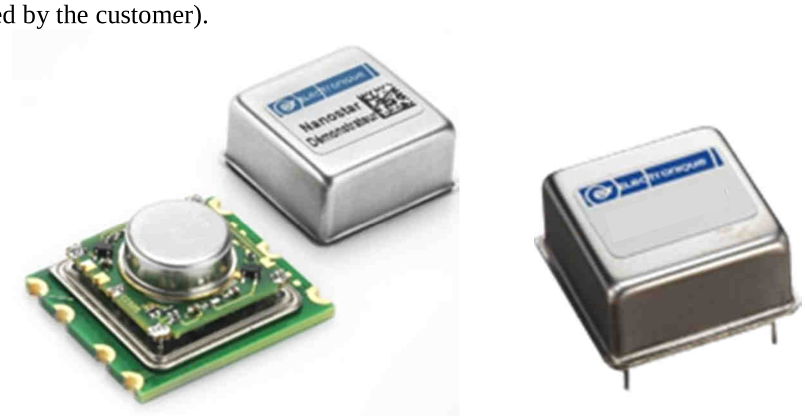

Fig. 1. nanOSTAR-SP SMD/TH versions

The oscillator incorporates a frequency multiplier function, which allows to cover a relatively large frequency range. Thus, the range covered starts from 10MHz up to 240MHz. For the nanOSTAR-SP OCXO, the frequencies above 60MHz are obtained by frequency multiplication.
The standard frequencies are 10, 20, 50, 60, 100 & 120MHz. Oscillators equipped with these standard frequencies can be delivered quickly.
Other frequencies can be addressed, with a slightly longer development and manufacturing time.

Environmental constraints have been taken into account in the design of the product. Thus, the oscillator is able to operate and survive, without degradation of performance, to:

Table 1: Standard environmental constraints for nanOSTAR-SP

Environmental constraints	Standard level (higher level may be requested)
Temperature range	[-40, +85] °C
Random vibration	12 gRMS in [10-2,000] Hz
Shocks	100g 6ms
Total ionization dose	50 krad

All these constraints have been simulated in order to get sufficient design margins to guarantee long-term performance and reliability.

IN HOUSE CRYSTAL MANUFACTURING

The nanOSTAR-SP oscillator is manufactured in compliance with MIL-PRF-55310 standard. Crystal resonators are using SC cut swept material and are manufactured in compliance with ESCC3501 LAT2 level B and our internal PID.

THERMOMECHANICAL PERFORMANCES

The following sub-chapters will present the main simulations results of the nanOSTAR-SP OCXO in Trough Hole (TH) package.

Power reduction

Thanks to the simulation, conduction losses in the package have been reduced. The final optimization leads to reduce the overall power consumption. The power consumption in steady state is in the range of 700mW at + 25°C. The Figure **2** is a simulation of conduction modes inside the OCXO. These modes have been minimized, while guaranteeing frequencies resonances of the printed circuit (PCB) greater than 2 kHz.

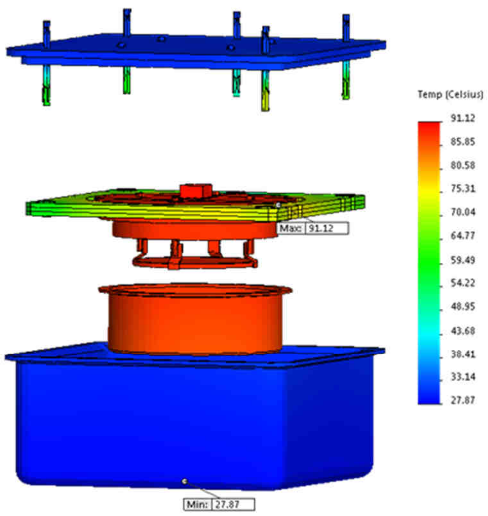

Figure 2: Simulated conduction modes in the package

Mechanical structure and frequency resonances

The mechanical structure of the OCXO has been simulated to limit the resonance frequencies of the PCB in the frequency range of 10 to 2,000 Hz. Thanks to simulations the natural resonant frequency of the oscillator has been rejected above 2,000 Hz (Figure **3**).

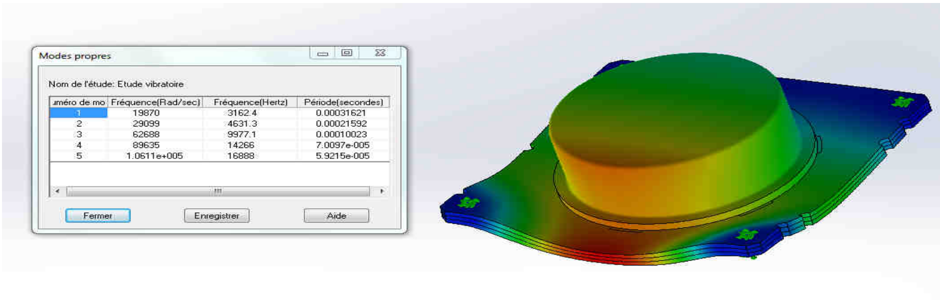

Figure 3: Result of resonance frequency simulations

ELECTRICAL PERFORMANCES

The following sub-chapters will present main experimental test results of the nanOSTAR-SP OCXO in the 10 MHz and 100MHz versions.

Frequency stability versus temperature

The OCXO performances are guaranteed in the range of [-20, +70]°C. However, it is operable in a wider temperature range, for example [-40, +85]°C.
Thanks to thermal simulations and to its mechanical structure, the oscillator is not so sensitive to external temperature, in comparison to his volume and mass. The crystal resonator, as well as electronics, sensitive to temperature variations, is thermostated at a quasi-fixed temperature. This structure makes it possible to minimize the influence of the external temperature on the frequency stability.
The Figure **4** and Figure **5** present frequency stabilities versus temperature results on OCXOs at 10MHz and 100MHz (50MHz multiplied by 2), as a function of a temperature rise/fall cycle, with a ±0.5°C/min thermal gradient.

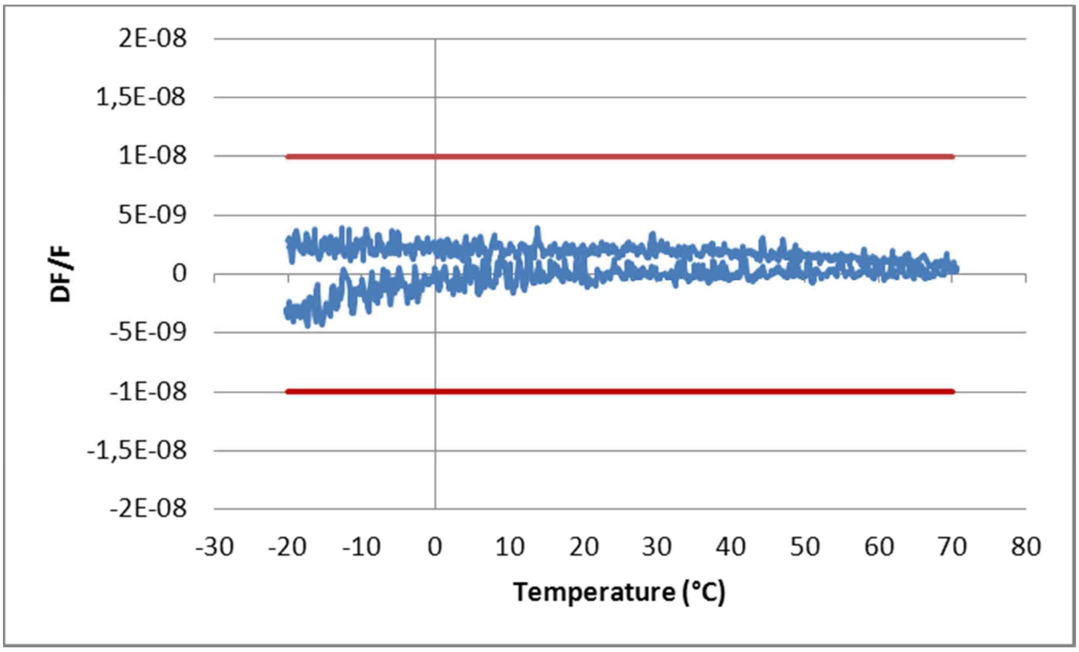

Figure 4: Frequency stability vs temperature for a 10MHz nanOSTAR-SP OCXO (specification in red)

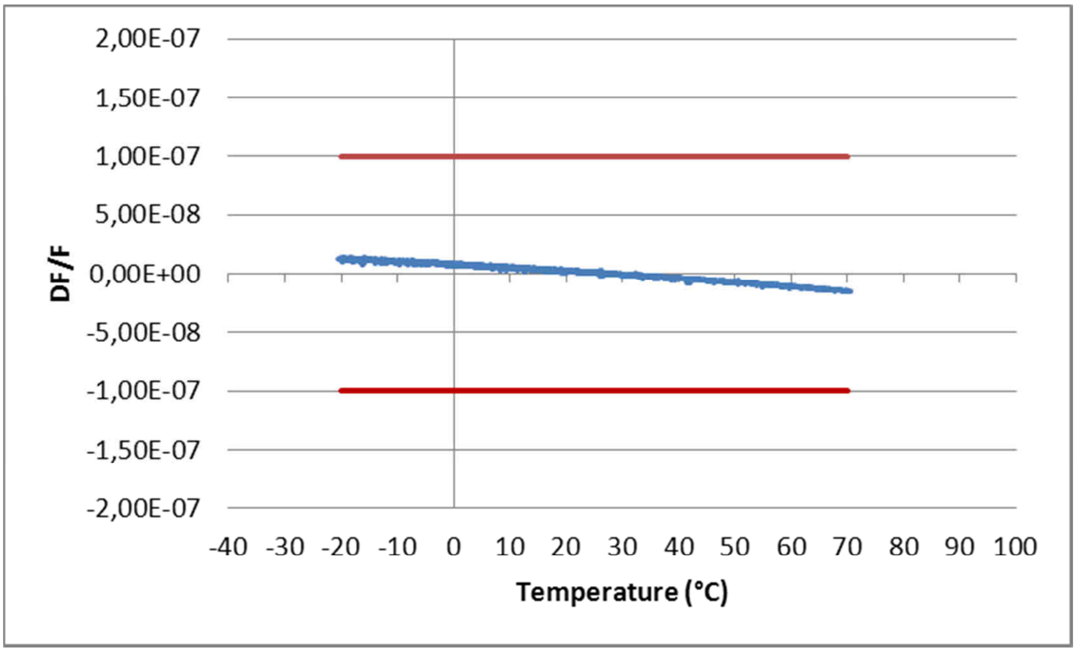

Figure 5: Frequency stability vs temperature for a 100MHz nanOSTAR-SP OCXO (specification in red)

Frequency stability versus voltage variation

The nanOSTAR-SP oscillator integrates a low-noise voltage regulator, ensuring excellent noise rejection of power supplies, as well as low sensitivity to external voltage variations. This sensitivity is critical for OCXOs, this is why ARE has chosen to add this internal regulator.

The Figure **6** shows the frequency variation for a ±5% variation of the supply voltage. The relative frequency variation is well below to $\pm 5.10^{-9}$.

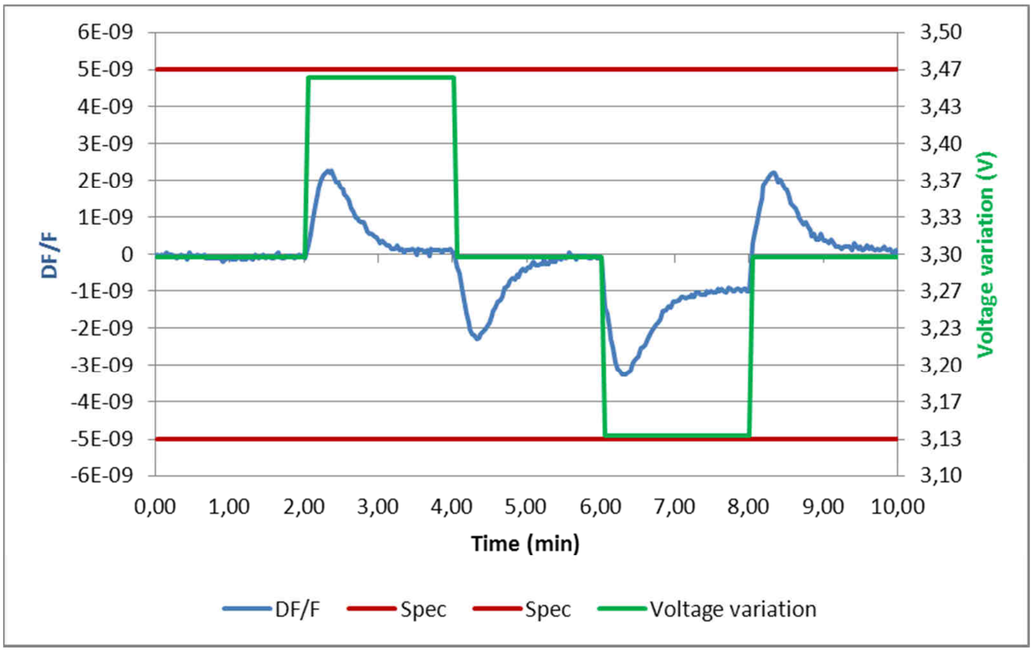

Figure 6: Frequency stability versus voltage variation

Phase noise and accelerometric sensitivity

The SC cut crystal resonators are encapsulated in TO-8 package. This design guarantees very low accelerometric sensitivity (between 2.10^{-10}/g and 5.10^{-10} total gamma), a state-of-the-art phase noise as well as a very low aging.

The phase noise curves (Figure **7**, Figure **8**) illustrate the different phase noise performance obtained with the nanOSTAR-SP oscillator.

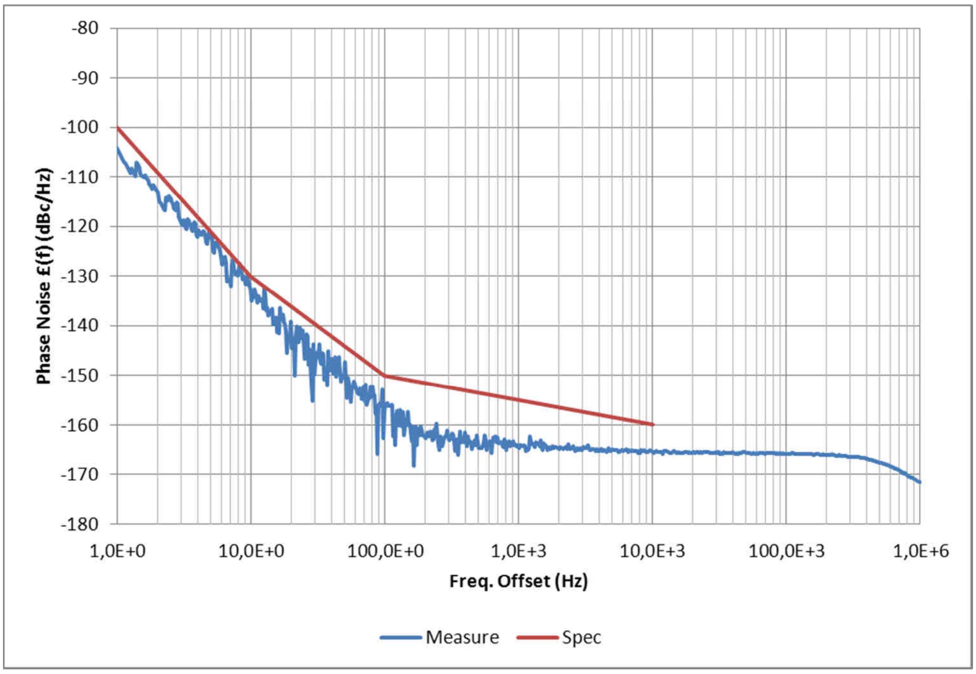

Figure 7: Phase noise performance on 10 MHz nanOSTAR-SP OCXO (in red specification)

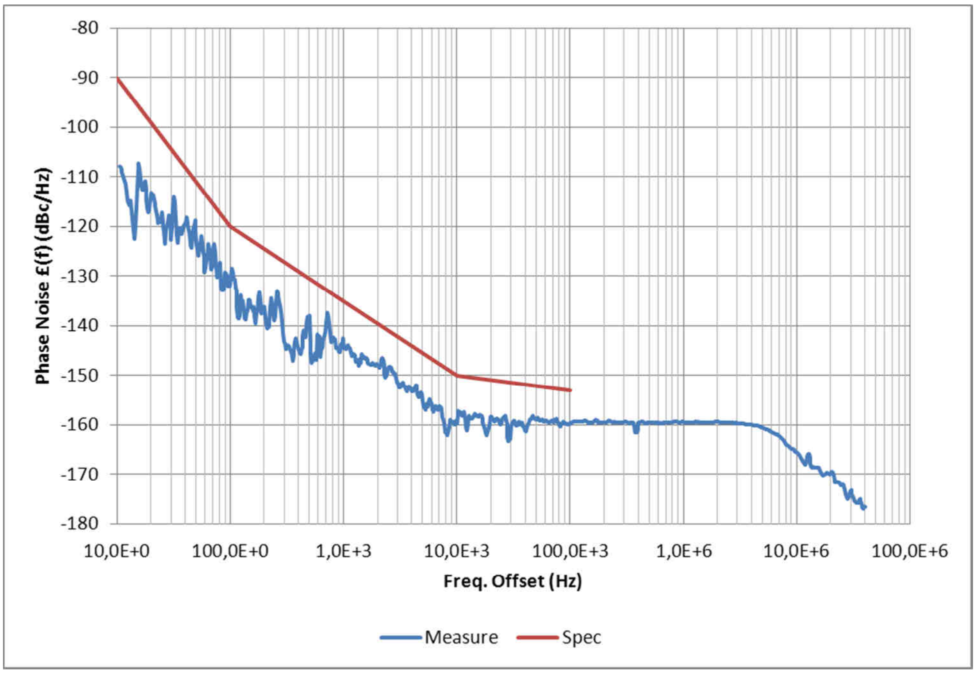

Figure 8: Phase noise performance on 100 MHz nanOSTAR-SP OCXO (in red specification)

Allan deviation

The Allan deviation is a synthesis of electrical and thermal performance of the oscillator. For integration times below one second, the electrical performance of the oscillator predominates. For integration times greater than one second, thermal performance predominates.
The thermal structure stability of the oscillator, as well as optimizations performed on the oscillator electronic lead to an excellent result in terms of Allan deviation, considering both dimensions and mass of the product.
The Figure **9** plots the Allan deviation obtained on a 10 MHz nanOSTAR-SP OCXO.

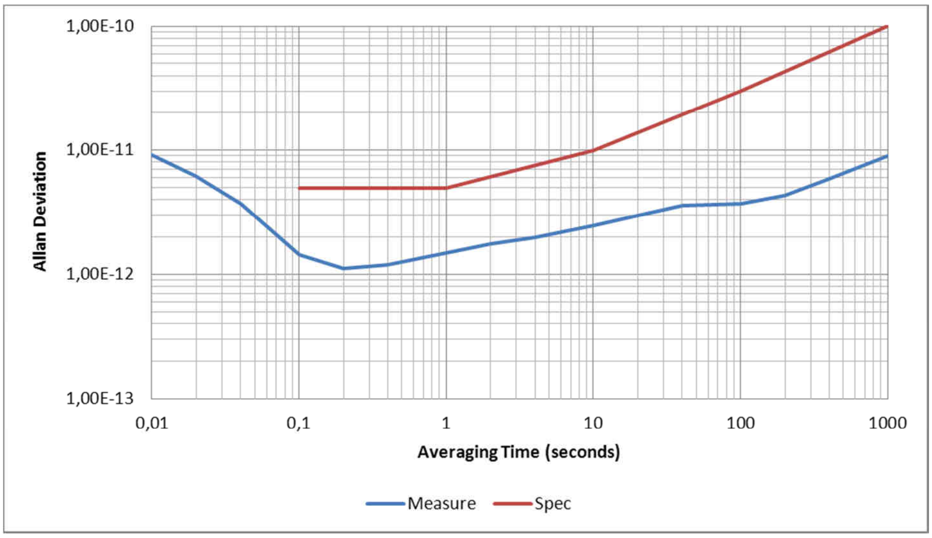

Figure 9: Allan deviation of a 10 MHz nanOSTAR-SP OCXO (in red specification)

Long term stability

ARE manufactures its own quartz resonators in order to ensure total control of the most critical component inside an oscillator. This high skill, coupled with precise and meticulous manufacturing process and control, provides one of the best long-term aging performances of the market. Thus, ARE is able to guarantee an aging better than $\pm 6.10^{-8}$ over 5 years on 10MHz version, and less than $\pm 8.10^{-7}$ for versions between 50 and 240 MHz.
The Figure **10** plots the aging of a nanOSTAR-SP at 10MHz (in blue), under metrological conditions (+25°C ±2°C). The curves in red are the specification at 10 MHz. The green and orange lines are extrapolations in better and worst cases.

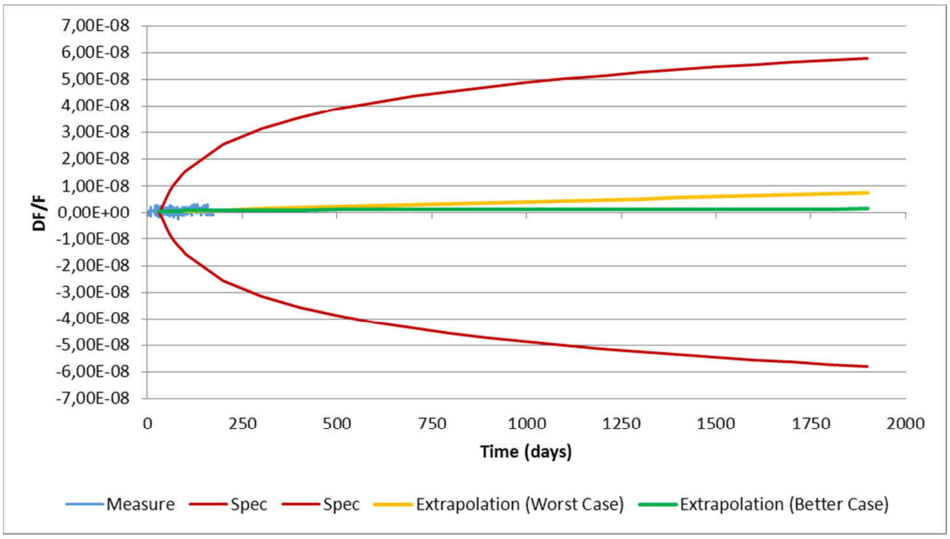

Figure 10: Typical aging of 10 MHz nanOSTAR-SP OCXO

The Figure **11** plots the aging of a nanOSTAR-SP at 100MHz (50MHz x2), under metrological conditions (+25°C ±2°C)

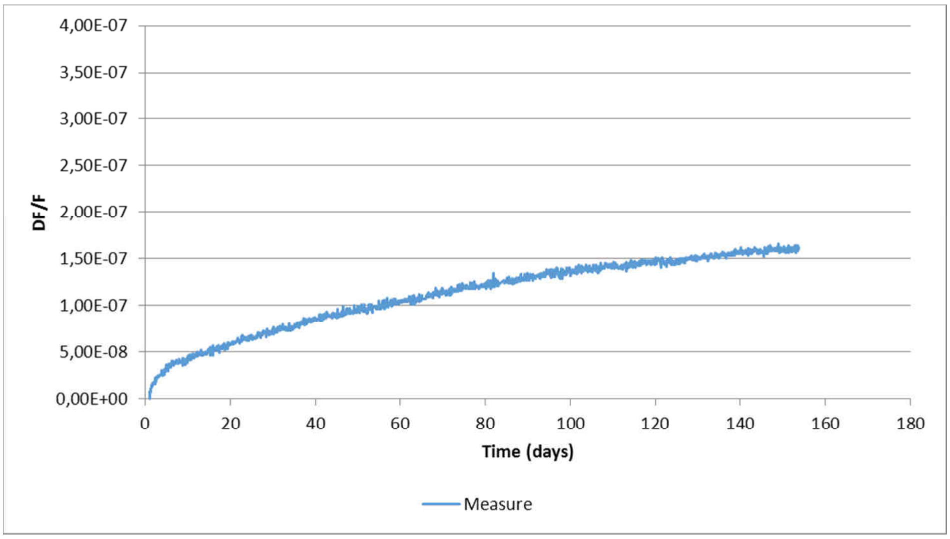

Figure 11: Typical aging of 100 MHz nanOSTAR-SP OCXO

The Figure **12** plots the aging of a nanOSTAR-SP at 100MHz (in blue), under metrological conditions (+25°C ±2°C). The curves in red are the specification at 100 MHz. The green and orange lines are extrapolation in better and worst case.

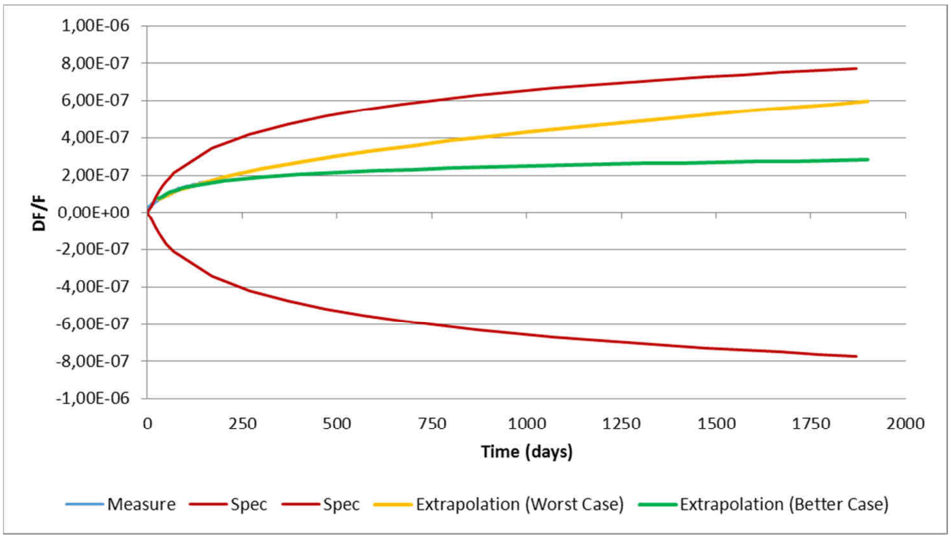

Figure 12: Extrapolation of 100 MHz OCXO

RELIABILITY RESULT

The MTBF of the nanOSTAR-SP oscillator is estimated at more than 600,000 hours according to MIL-HDBK-217F2. This standard is no longer upgraded, and it does not take into account the arrival of COTS in the space environment.
In order to verify the long-term reliability of this OCXO, ARE has performed a long qualification program. This program consists of temperature cycling [-40, +85] ° C and switching the power supply of oscillators every 15 minutes. Random vibrations are periodically performed on all tested products.
Twenty 10 MHz OCXOs have been submitted to this qualification program.

By considering a LEO with a cycle every 90 minutes with a temperature cycling of [-20, +70]°C, ARE reliability tests give an estimated MTBF of over 900,000 hours at 63%, either more than 600,000 LEO orbits.

The Figure **13** traces a reliability estimation of OCXO 10MHz

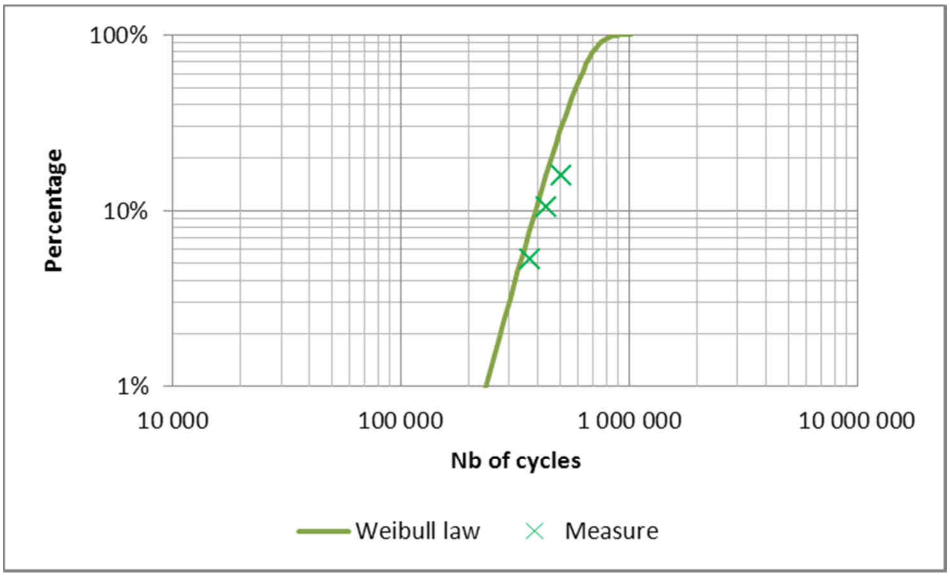

Figure 13: Reliability estimation of 10MHz OCXO

During reliability program tests, nominal frequency measurements were performed. These measurements make it possible to check the long-term aging of the oscillators.
By keeping the low orbit parameters used previously, the following curves measure the accelerated aging of the different products.
The Figure **14** traces the frequency measurements of the different products. The red curves show the long term specifications.

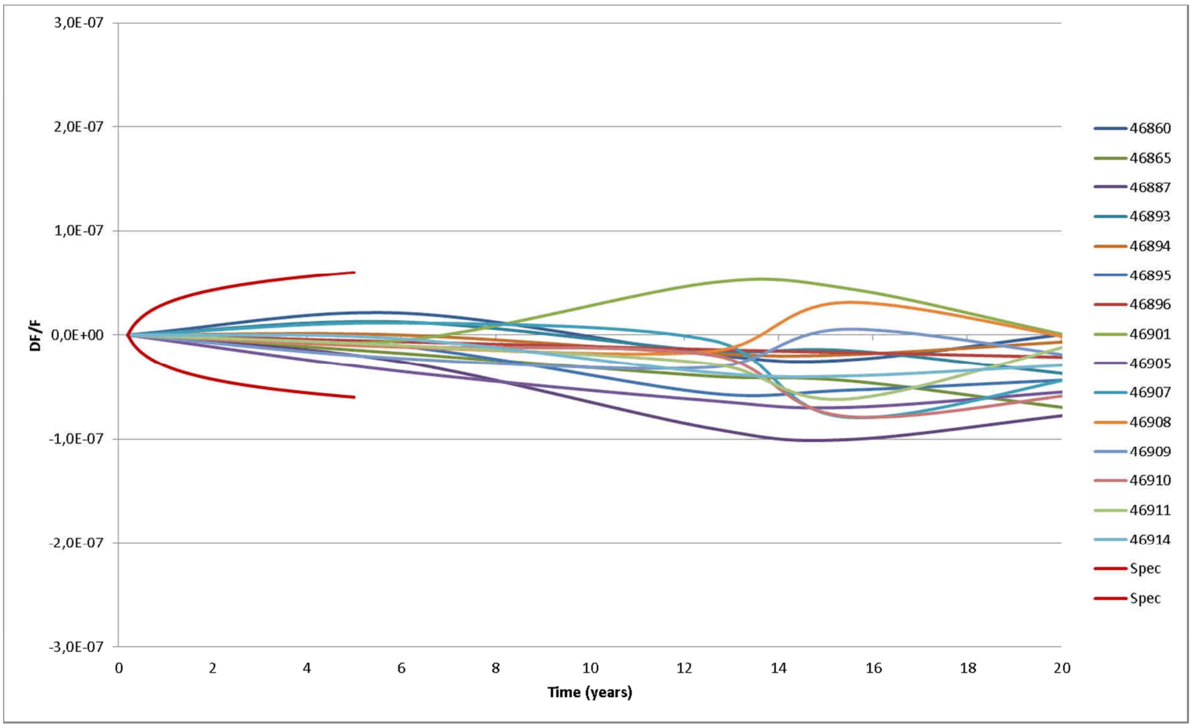

Figure 14: Long term aging on 10MHz products

CONCLUSION

The "New space" requirements require a triptych (mass, volume and consumption) as optimized as possible, while ensuring increased reliability, state-of-the-art RF performances, and a delivery time of a few months.

The response of AR Electronique to these different requirements is the nanOSTAR-SP 10-240MHz product line.
The following points resume main characteristics:

- Wide frequency range covered between 10MHz and 240MHz.
- Low volume (<5cm^3)
- Low mass (<10 grams)
- Very short delivery time (4-7 months)
- Reduced power consumption (700mW at +25°C)
- Power supply between +3.3V to +5V
- Excellent frequency stability under temperature
- State of the art phase noise performances
- State of the art Allan deviation up to 1,000 seconds

The internal quality requirements of AR Electronique in the design and manufacturing crystal resonators and oscillators, guarantee to our customers an excellent long-term reliability of our products.

In order to determine the maximum Single Event Effects (SEE) immunity, an evaluation program is in progress with the support of the French Space Agency (CNES).