A Miniaturized OCXO for Space Application with Low Radiation Sensitivity

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***Abstract*—The CNES engaged in 1996 a program of development of miniature OCXO for space applications. In an objective of costs reduction, it was decided to use professional components (COTS) which were qualified by the methods of the aggravated tests . The first oscillator developed is a DIL 14 case OCXO called EWOS-513 which flies already on the Rosetta space probe and which is embarked on all micro-satellite Myriade space bus of the CNES. This oscillator exhibits a typical short term stability of a few 10-11 over 1s, with a thermal sensitivity of 10^{-9} /°C and an aging of a few 10^{-10} per day.**

However this first generation of oscillators had an important radiation sensitivity, of electronic origin, which led to a fast and important degradation of its short term stability. The TES company decided to realized some studies in order to reduce this sensitivity and their results were so encouraging that we have developed a second generation of oscillator, the EWOS-513/B.

The qualification campaign by aggravated tests has been just completed by tests in irradiations with low dose rate up to 100 kRad. The results obtained are very favorable : The short term stability degradation observed on the preceding generation of oscillator have completely disappeared and the oscillators preserve its performances up to 100 kRad. But beyond this first conclusion, it arises from these measurements a strong homogeneity of the behaviors, a low dose sensitivity and a relative insensitivity to fragmented irradiations. This contrast with all that was observed until now, more especially when we know that the resonators used are not swept.

This paper, after a rapid presentation of the EWOS-513/B oscillator, will describe the conditions of tests and the results obtained. In conclusion, it will try to make proposals to go further in the comprehension of this problem.

I. Introduction

A. Professional oscillators for space applications

The Nineties were the occasion of a notable change in the space industry with a renewed interest for smaller satellites (in opposition to the large telecommunication payloads). That led all contributors of this sector to a great effort in terms of saving weight, power consumption and cost.

The principal explored way was the use of professional components rather than space qualified ones. That gave access to more integrated technologies authorizing significant profits mainly on costs and delays of development. That also brought us to reconsider the methods of qualification of space equipment. Traditional methods, based on the individual qualification of each component or process and on the traceability of the suppliers were not applicable any more. It was thus necessary to imagine some new ways, by taking as a starting point what was made in industry, in particular aeronautical and automobile.

B. A first application : The EWOS 513

First products to be developed at CNES from such an approach were miniature OCXO derived from those produced on a large scale for ARGOS/SARSAT beacons by TES Electronic Solutions (Formerly SOREP, then THALES Microelectronics). Twelve OCXO, called EWOS 513, where involved in the qualification process based on the Highly Accelerated Tests [1]. Tests were successful, expect for radiations : Whereas first tests up to 1 kRad were perfectly conclusive, following tests up to 50 kRad with high dose rate showed a strong degradation of the short term noise. This led us to carry out tests with a lower dose rate and continuous measurement of frequency and short term stability. Unfortunately, several series of tests with different rates confirmed this degradation of the stability (Figure 1). The origin of this degradation was identified as being related to the technology used for the ASIC.

This degradation was however compatible with applications concerned, mainly receivers and transmitters for remote control and telemetry. EWOS 513 have then been used on the ROSETTA and Deep Impact space probes and on all CNES micro satellites (Myriad Platform) : A total of one hundred oscillators have been delivered for space applications.

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Despite that first success and because this first generation of EWOS 513 suffers on high radiation sensitivity, it has been decided to developed an new generation of micro OCXO, the EWOS 513/B.

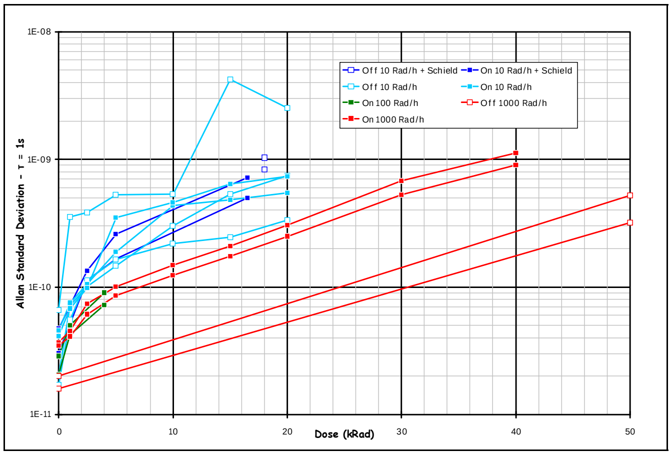

Figure 1. Micro-OCXO EWOS 513/B

II. THE MICRO-OCXO EWOS 513/B

The EWOS 0513 is a very small size and low power OCXO especially designed for space application [2]. It is mainly made up of a quartz crystal resonator and a specific integrated circuit (ASIC). The crystal is a 10 MHz, fundamental mode AT cut resonator with a Q factor of at least 30 000, housed in a SMD ceramic package. Quartz crystal are not swept. In addition to being the oscillator loop and the output amplifier, the ASIC, directly stuck on the resonator's package, is used for heating and controlling the temperature of the crystal unit and the electronic. The EWOS 0513 is housed in an hermetic metallic DIL package.

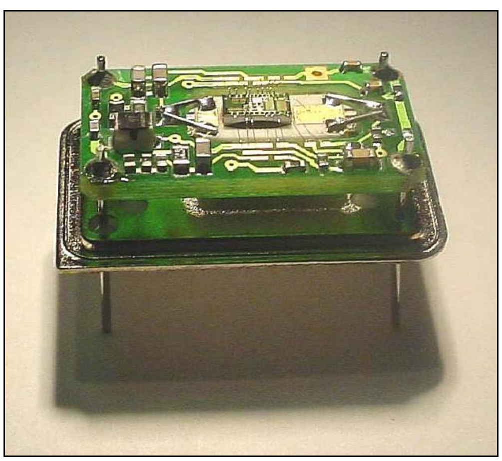

Figure 2. Micro-OCXO EWOS 513/B

The main difference between the two generations of EWOS 513 concern the ASIC. For different reasons, TES has decided to develop a new one. Even if this new design was mainly for professional use and then not rad hardened, some specific care have been taken to take into account the results from the radiation tests held on the first generation of OCXO.

In 2004, we have started a new qualification process. Twenty four oscillators were implied. Their typical performances, measured before the radiation campaign, are presented in Table 1.

TABLE I. EWOS 513/B – REQUIREMENTS AND PERFORMANCES

Item	EWOS 513		
	Req.	***Avg.***[a]	***Unit***
Frequency Tuning	10 ±5	10 >±7	MHz ppm
Power supply Consumption (vacuum, -30°C)	5 300	- 220	V mW
Stability (vacuum) Allan (1s) In [-30 / +60 °C] Slope/mn (with 0,5 °C/mn) Per day Per year	 10 0.10 ±10 1 0.25	 2 0.06 ±6 - -	 10^{-11} ppm 10^{-10}/mn 10^{-9} ppm
Phase noise @ 10 MHz 10 Hz 100 Hz 1000 Hz	 - - -130	 -109 -136 -148	 dBc/Hz dBc/Hz dBc/Hz
Mass	4.2		g
Volume	1.6		cm^3
Operating Conditions Temperature Random vibrations Radiation	 [-30, +60] 0.732 100		 °C g^2/Hz kRad

a. Average value of the 24 OCXO

III. RADIATION TEST

A. Test description

The radiation test setup results from the passed experience of tests on miniaturized OCXO. Thus, we have decided to make continuous measurement of both frequency and short term stability. Off/On cycles are also done every 25 kRad / We learned form previous tests that some oscillators which have perfectly run up to 100 kRad were not able to start up after the end of the test.

Our test bench have 8 measurement channels. In order to adapt measurements to the test phase, either steady state or transient behavior, two acquisition rates are used :

- A fast acquisition rate, with a period of 40 seconds that is to say 5 s per oscillator to switch on the channel, allow frequency stabilization at the test bench level and make one frequency measurement, with a 1 s gate.
- A slow acquisition rate , with a period of 8 minutes, that is to say 60 s per oscillator to switch on the channel, allow frequency stabilization at the test bench level and make 30 frequency measurement with a 1 s gate. We only store the average value of the frequency and the Allan standard deviation computed from those 30 points.

The profile of the tests is thus the following :

- Simulation of a Earth low orbit : A few days with radiation of 40 minutes every 120 minutes with a radiation rate of 5 Rad/h (Fast acquisition rate) ;
- 25 kRad with a radiation rate of 50 Rad/h (Slow acquisition rate) followed by 25 On/Off ;
- Simulation of a low Earth orbit ;
- 25 kRad at 50 Rad/h followed by 25 On/Off ;
- Simulation of a low Earth orbit ;
- 25 kRad at 100 Rad/h followed by 25 On/Off ;
- 25 kRad at 100 Rad/h followed by 25 On/Off.

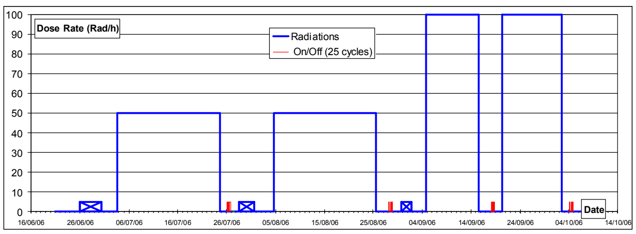

Figure 3. Test schedule

Thirteen oscillators were involved in the tests : Height have been irradiated with power supply switched on, the 5 others were switched off. For these last oscillators, there has not been continuous measurement but only a short term stability evaluation before and after the test.

The tests proceeded in a dedicated bunker at the ONERA/CERT/DESP in Toulouse. The bunker is controlled neither in humidity nor in temperature but profits from a natural insulation related to its situation (under ground, with one meter thick walls of concrete). The radiation source is a Cobalt 60 source. The change of the dose rate is made by modifying the distance between the source and the oscillators by displacement of the oscillators.

B. *Data analysis*

The analysis of measurements is made for the following items :

1) Global behavior of oscillators during the tests, with in particular an analysis of the evolution of the sensitivity with the radiation dose. For each oscillator, we calculate the sensitivity to the radiation dose at both the beginning and the end of each period of continuous irradiation. This sensitivity is evaluated by withdrawing estimated ageing of the oscillator. This ageing is calculated by linear regression over the first and last days of tests. The calculation of sensitivity is made 2 times with these two values of ageing.

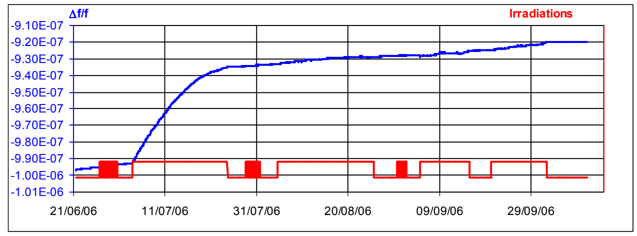

Figure 4. Global behavior (EWOS 513B – 0515/018)

2) Follow-up of the evolution of the short term stability of oscillators. Calculation is carried out over the same periods as those taken for the calculation of the sensitivity, i.e. a few days at the beginning and the end of each period of continuous irradiation.

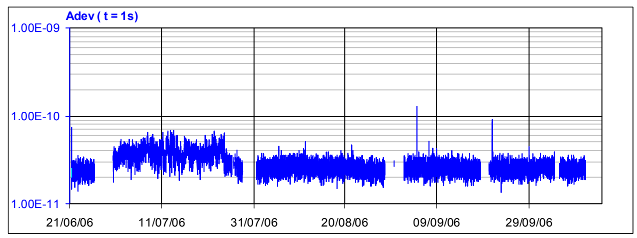

Figure 5. Short term stability (EWOS 513B – 0515/018)

3) Study of the behavior of oscillators during the fragmented radiations (LEO profile). The analysis, mainly qualitative, consists of a comparison of the behaviors of oscillators for the 3 periods of fragmented radiations (Figure 6). It comes out from this analysis that the effect of the radiations in this context is drowned in the oscillator noise and that it is not possible to detect any signature in the signal. One distinguishes only a first frequency jump at the build-up of the first radiation slot (Figure 7). Even an analysis made by averaging several cycles does not make it possible to highlight a modification of the behavior (Figure 8).

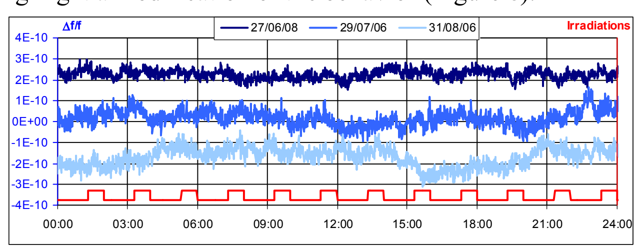

Figure 6. Last day of fragmented radiations at 0, 25 and 50 kRad

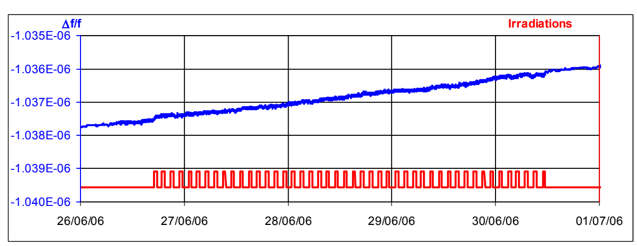

Figure 7. First fragmented radiations (EWOS 513B – 0515/018)

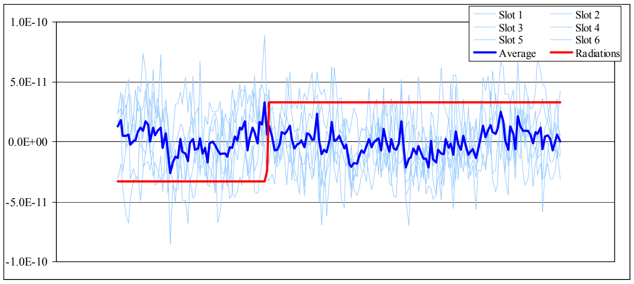

Figure 8. Superposition of radiation slots and average value (EWOS 513B – 0515/037)

C. *Main results*

The following tables draw up a summary of the results.

First, all oscillators present homogeneous behaviors and sensitivities, with a saturation of the sensitivity before 25 kRad (Table III). Then, the influence of radiations is drowned in the noise. No significant annealing is observed at the end of the test, the frequency shift induced by the radiations seems to be definitive. Taking, in the computation of this sensitivity, the value of drift at the beginning or the end of the test has no influence : About some 10^{-13} per Rad which is not significant in regards with our measurement uncertainty (Short term noise around 10^{-11}) and with the drift of the oscillator (some 10^{-11} per day at the end of the campaign). We can also observe that the sensitivity at the beginning of a new period of continuous radiation is very close of the one at the end of the previous period. Whereas that phenomenon has already been seen [3] and justifies preconditioning process for space applications, our measurements contrasts with usual observations, which report on strong dispersions in the behaviors and greater sensitivities despite that resonators are usually swept [4]

TABLE II. RADIATION SENSITIVITY
(Computed on the 5 last days of each continuous radiation period)

Oscillator	Sensitivity with drift removed, per Rad (Normal, with drift at the beginning of the test, italic with drift at the end)			
	25 kRad	*50 kRad*	*75 kRad*	*100 kRad*
0515-006	$9.0E^{-13}$ $1.1E^{-12}$	$-1.1E^{-13}$ $1.2E^{-13}$	$-0.3E^{-13}$ $0.8E^{-13}$	$0.5E^{-13}$ $1.6E^{-13}$
0515-011	$2.6E^{-13}$ $4.9E^{-13}$	$-1.2E^{-13}$ $1.0E^{-13}$	$2.0E^{-13}$ $3.1E^{-13}$	$2.4E^{-13}$ $3.5E^{-13}$
0515-018	$6.6E^{-13}$ $8.2E^{-13}$	$-2.3E^{-13}$ $-0.6E^{-13}$	$0.1E^{-13}$ $0.9E^{-13}$	$1.1E^{-13}$ $1.9E^{-13}$
0515-022	$1.7E^{-13}$ $2.5E^{-13}$	$2.5E^{-13}$ $3.3E^{-13}$	$2.6E^{-13}$ $3.0E^{-13}$	$2.7E^{-13}$ $3.1E^{-13}$
0515-027	$4.7E^{-13}$ $5.7E^{-13}$	$-1.7E^{-13}$ $-0.8E^{-13}$	$0.1E^{-13}$ $0.5E^{-13}$	$3.7E^{-13}$ $4.2E^{-13}$
0515-033	$-0.1E^{-13}$ $0.4E^{-13}$	$1.0E^{-13}$ $1.5E^{-13}$	$0.7E^{-13}$ $1.0E^{-13}$	$0.9E^{-13}$ 1.1E-^{13}
0515-034	$1.6E^{-13}$ $5.9E^{-13}$	$-4.7E^{-13}$ $-0.4E^{-13}$	$0.7E^{-13}$ $2.8E^{-13}$	$0.5E^{-13}$ $2.7E^{-13}$
0515-037	$-1.8E^{-13}$ $-0.4E^{-13}$	$-4.7E^{-13}$ $-3.3E^{-13}$	$-0.5E^{-13}$ $0.3E^{-13}$	$1.2E^{-13}$ $1.9E^{-13}$

Table III shows an important improvement of the long term drift between the beginning and the end of the test. Nevertheless, we assume that it is more a natural aging effect than a radiation effect : Oscillators were very "young" at the beginning of test and it was their first period of continuous operations.

TABLE III. LONG TERM DRIFT
(Computed on the 3 first days and the 5 last days of the test)

Oscillator	Long term drift, per day (Requirement – Typical values : $0.25E^{-6}$ per year or $7E^{-10}$ per day)		Frequency Shift for 100 kRad
	Beginning	*End*	
0515-006	$2.9E^{-10}$	$1.6E^{-11}$	$6.0E^{-8}$
0515-011	$2.9E^{-10}$	$2.0E^{-11}$	$6.2E^{-8}$
0515-018	$2.5E^{-10}$	$5.1E^{-11}$	$7.4E^{-8}$
0515-022	$0.5E^{-10}$	$-5.1E^{-11}$	$8.1E^{-8}$
0515-027	$1.4E^{-10}$	$2.5E^{-11}$	$5.7E^{-8}$
0515-033	$1.5E^{-10}$	$8.9E^{-11}$	$5.1E^{-8}$
0515-034	$6.6E^{-10}$	$14.4E^{-11}$	$5.1E^{-8}$
0515-037	$1.7E^{-10}$	$< 0.1E^{-11}$	$4.8E^{-8}$

TABLE IV. SHORT TERM STABILITY
(Computed on the last day of each continuous radiation period)

N°	Short term stability Allan Standard deviation for $\tau = 1$ s					
	Before	*25 kRad*	*50 kRad*	*75 kRad*	*100 kRad*	*After*
006	$1.8E^{-11}$	$6.9E^{-11}$	$16.7E^{-11}$	$11.4E^{-11}$	$13.0E^{-11}$	$3.4E^{-11}$
011	$1.9E^{-11}$	$8.3E^{-11}$	$12.7E^{-11}$	$6.9E^{-11}$	$6.5E^{-11}$	$2.7E^{-11}$
018	$2.3E^{-11}$	$4.1E^{-11}$	$2.4E^{-11}$	$2.6E^{-11}$	$9.6E^{-11}$	$2.4E^{-11}$
022	$2.2E^{-11}$	$4.1E^{-11}$	$4.0E^{-11}$	$4.7E^{-11}$	$4.7E^{-11}$	$3.1E^{-11}$
027	$2.5E^{-11}$	$2.8E^{-11}$	$2.7E^{-11}$	$2.9E^{-11}$	$3.7E^{-11}$	$2.3E^{-11}$
033	$2.4E^{-11}$	$2.7E^{-11}$	$3.1E^{-11}$	$2.6E^{-11}$	$2.5E^{-11}$	$2.2E^{-11}$
034	$2.7E^{-11}$	$4.6E^{-11}$	$5.5E^{-11}$	$6.0E^{-11}$	$4.1E^{-11}$	$2.6E^{-11}$
037	$2.7E^{-11}$	$10.4E^{-11}$	$9.0E^{-11}$	$9.7E^{-11}$	$12.0E^{-11}$	$2.8E^{-11}$

TABLE V. SHORT TERM STABILITY
(Oscillators switched off)

Oscillator	Short term stability Allan Standard deviation for $\tau = 1$ s	
	Before	*After*
0515-010	$2.1E^{-11}$	$2.1E^{-11}$
0515-014	$2.1E^{-11}$	$2.1E^{-11}$
0515-020	$1.9E^{-11}$	$2.7E^{-11}$
0515-038	$2.0E^{-11}$	$1.8E^{-11}$
0515-039	$1.9E^{-11}$	$2.1E^{-11}$

Analysis of short term stability results is more difficult. If we observe some large changes during the test (Table IV), its seems that their origin is more a test bench problem (oscillator test support) than a real degradation of the oscillators. Measurements made after the end of the radiation test show first that all the performances meet the requirements and then that results are very dependent of the test support use for the measurement. Measurements made on the oscillators that were switched off along the test do not show either degradation of the short term stability (Table V).

After this radiation campaign, we have performed a complete check up of the oscillators performances, including thermal test and phase noise. Comparison of these measurements with those made before the campaign does not show any differences in the behavior of the oscillator.

IV. CONCLUSION

First of all, these tests show that the EWOS 513/B could resist without loss of performance to the space environment, including radiations up to 100 kRad. But they also highlighted new phenomena : Although based on non swept resonators, their behaviors are very homogeneous and the measured sensitivities are quickly drowned in the noise of the oscillators. Even if that was not the goal of these tests, and in order to go further in the comprehension of this phenomenon, it is planned to include this kind of resonators, irradiated or not, in a broader action taken by the CNES on the analysis of the causes of the radiation sensitivity of the quartz resonators [5].

In the meanwhile, the EWOS 513/B is declared “good for flight” and will contribute, we hope for it, to many space missions.

ACKNOWLEDGMENT

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