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HIGH STABILITY, VERY LOW PHASE NOISE, PULSAR-SP USO

Emmanuel Girardet[(1)], Sébastien Renaud[(1)], Pierre Boillot[(1)]

[(1)] AR ELECTRONIQUE
Parc La Fayette – 16 rue La Fayette
F-25000 BESANCON, France
Email: emmanuel.girardet@ar-e.com

INTRODUCTION

Increasing improvements needs in Earth observation satellites with Synthetic Aperture Radar (SAR), ultra-stable clocks, synthesizers, radars, scientific instruments and Solar System Exploration require better reference oscillators, among other things. These space applications need higher reference frequency with lower phase noise as well as high stability performances.

In this context, AR Electronique (ARE) has designed a full class S PULSAR-SP USO family which covers a frequency range from 10 MHz to 120 MHz and guarantees a very low phase noise close to the carrier together with high stability performances.

This paper will first present a short product description of the space oscillator. Then a presentation of the main electrical performances will be given. Lastly, the qualification results as well as the frequency range opportunities will be exposed.

PRODUCT DESCRIPTION

The PULSAR-SP USO is an Oven-Controlled Crystal Oscillator (OCXO) in a 50 mm x 50 mm x 25 mm milled aluminum package, as shown in the Fig. 1.

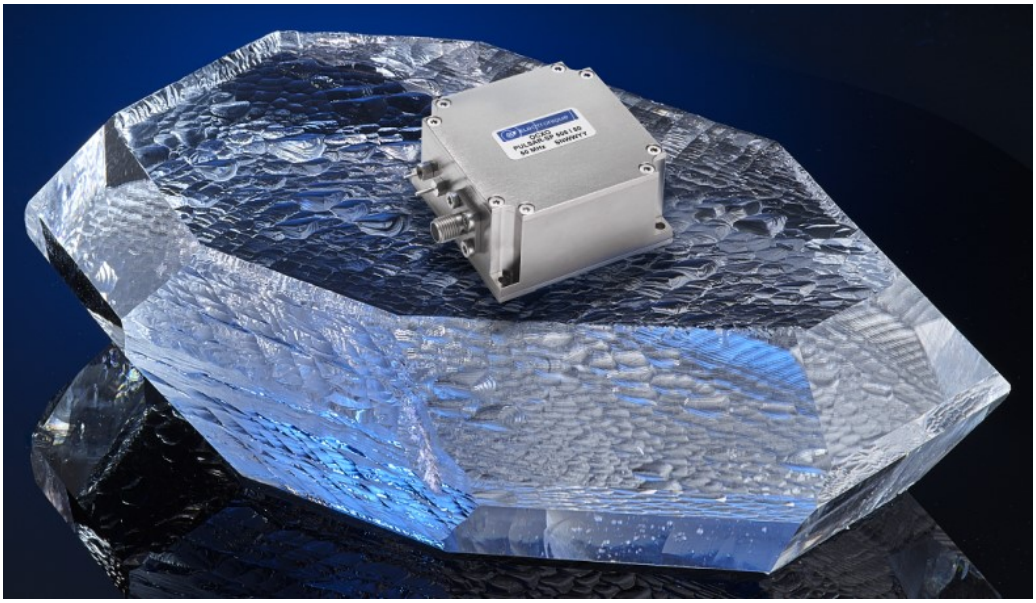

Fig. 1. PULSAR-SP

The thermal structure of the oscillator is based on an oven part containing the resonator and the sensitive electronic. It regulates finely their temperature. The typical operating temperature range is [-15°C; +65°C].

Thanks to a modular design, this USO family covers a frequency range of 10 MHz to 60 MHz in direct frequency and up to 120 MHz with internal frequency multiplier.

The PULSAR-SP USO is an ITAR-Free product.

In-House Crystal Resonator

This oscillator is based on ARE manufactured SC-cut overtone crystal resonator with low g-sensitivity coming from defence and airborne products heritage. The resonator uses swept material, as requested in space application. Crystals has been qualified according to ESA ESCC3501 LAT 2, Level B method.

Radiation Hardness

The oscillator has been designed for the space environment with vacuum and radiation. Technical analyses such as reliability and worst case and radiation analysis have demonstrated the robustness of the product during life time and against radiation. The USO withstands the Total Ionizing Dose (TID) of 100 kRad, low dose rate, received during a 18 years mission in orbit and endures the Single Event Effect (SEE) without destruction of any electronic component. The oscillator has no Single Event Latch-up (SEL) up to Linear Energy Transfert threshold (LET) equal to 60 MeV·cm²/mg.

Product Reliability

The reliability of the Class-S oscillator is about 135 Failure In Time (FIT) per 1.0 E+9 hours or a Mean Time Between Failure (MTBF) equal to 7.4 E+6 hours. The Fig. 2 shows the distribution of the failures versus component type.

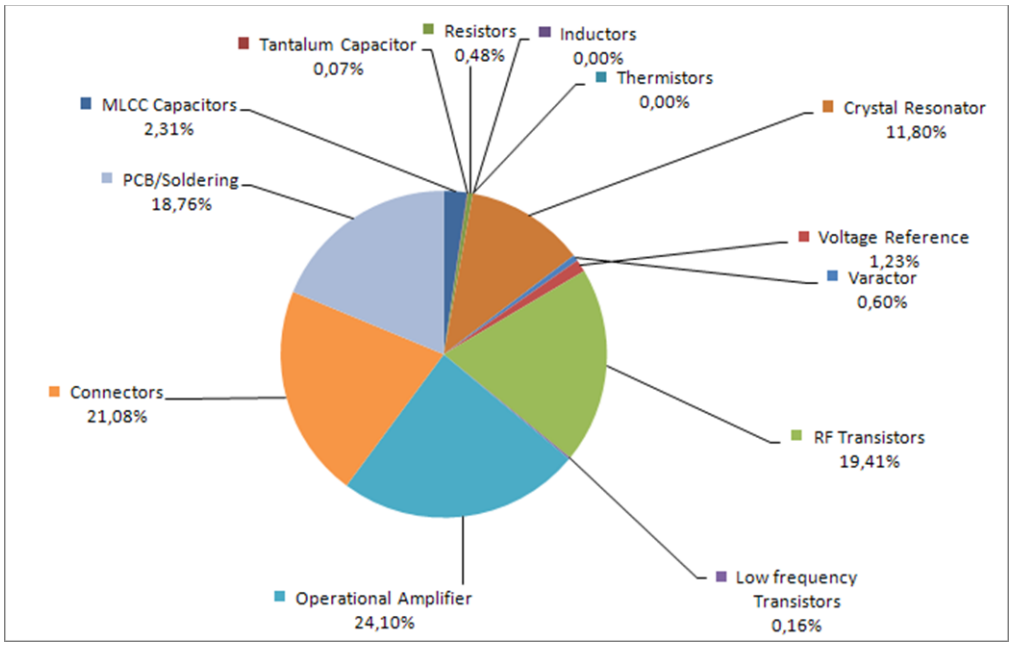

Fig. 2. Product failures distribution

ELECTRICAL PERFORMANCES

Following sub-chapters will present the main experimental test results of the PULSAR-SP USO in the 50 MHz OCXO version.

Frequency Stability vs. Temperature under vacuum

The frequency stability versus temperature is tested under vacuum, with pressure below 5.0 E-7 bar and a positive temperature gradient of 0.2°C per minute. In the range [-15°C; +65°C], the frequency stability is better than 3.0 E-9 peak to peak, as shown on Fig. 3.

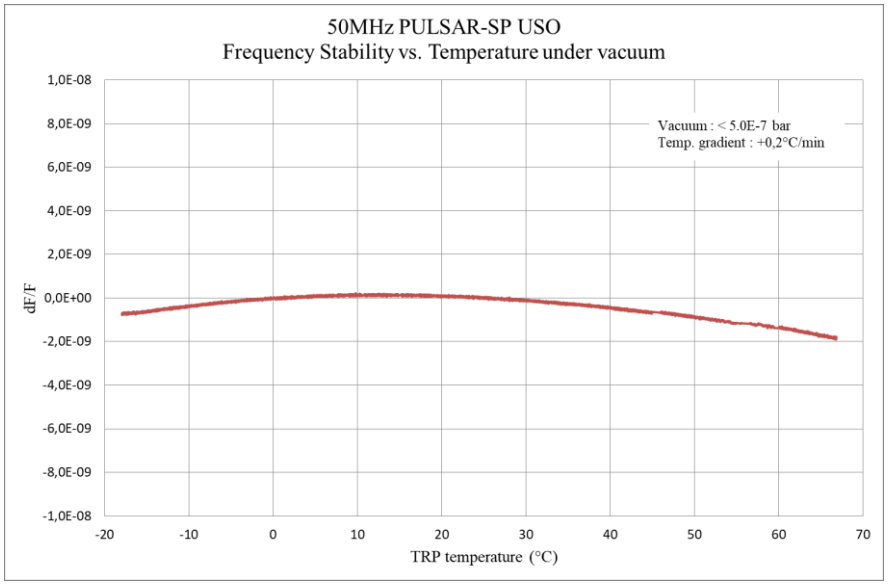

Fig. 3. Frequency stability vs. temperature under vacuum

Long-Term Stability (Aging)

This oscillator offers a very good compromise between aging performance and output frequency. At 50 MHz, after 30 days of aging, the long-term stability is in the order of a few ppb per month, as shown on the Fig. 4. This value is not far from the typical aging results on a good 10MHz OCXO.

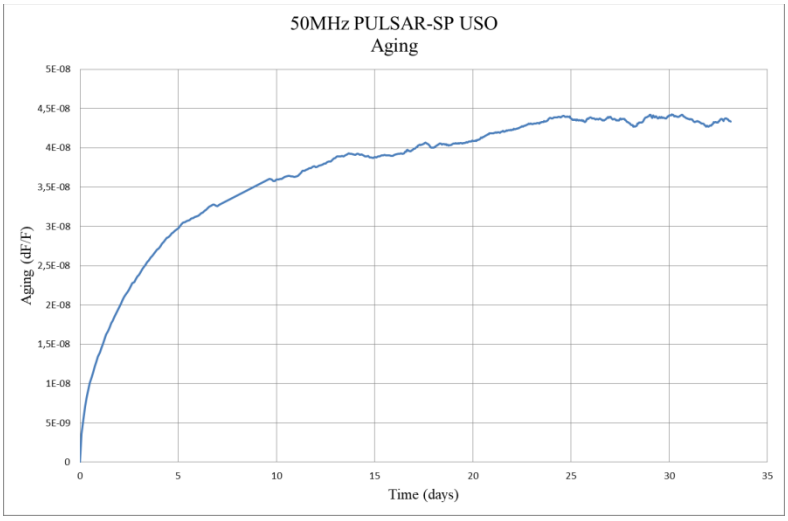

Fig. 4. Long-Term Stability (Aging)

Acceleration Sensitivity

The 50 MHz USO is based on an ARE manufactured crystal with low g-sensitivity. The design of this resonator is coming from defence and airborne products heritage. The fig. 5 shows the worst axis acceleration sensitivity of a batch of 47 crystals. G-sensitivity is below or equal than 5.0 E-10 per g for 90 percent of the batch.

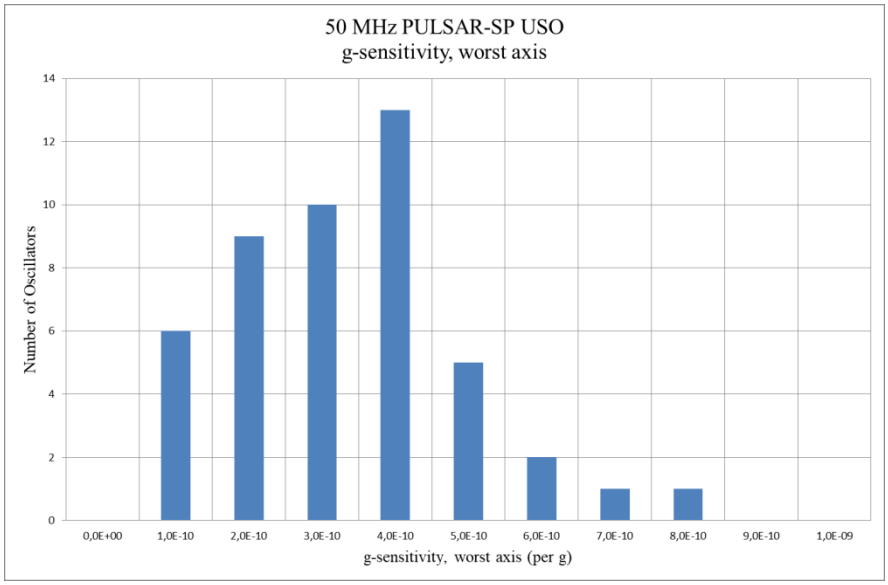

Fig. 5. Acceleration Sensitivity, worst axis

Phase Noise

Thanks to a high-Q factor ARE Crystal resonator coupled with a low noise electronic, the PULSAR-SP oscillator guarantees a very low phase noise close to the carrier. The Fig. 6 shows the typical phase noise plot of the 50 MHz USO. The close-in phase noise in the range [1 Hz ; 100 Hz] is significantly low.

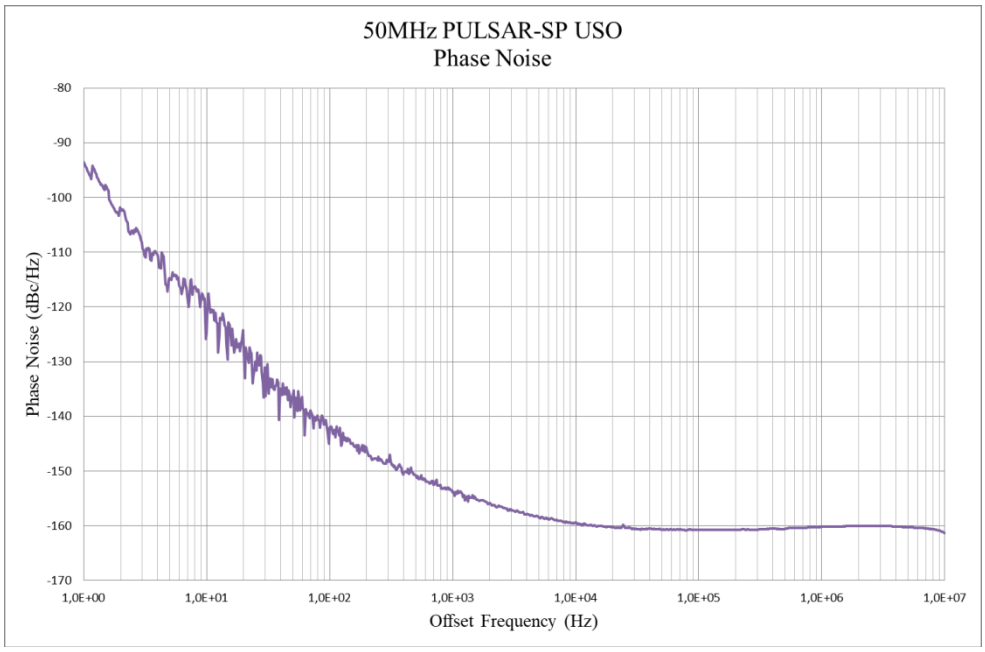

Fig. 6. Phase Noise

Short-Term Stability (Allan Deviation)

The combination of a high thermal stability, a high-Q factor Crystal resonator with low aging together with a low noise electronic gives to the USO an outstanding short-term stability behavior at 50 MHz, as shown on the fig. 7. The Allan deviation between 1 second and 1000 second is particularly low.

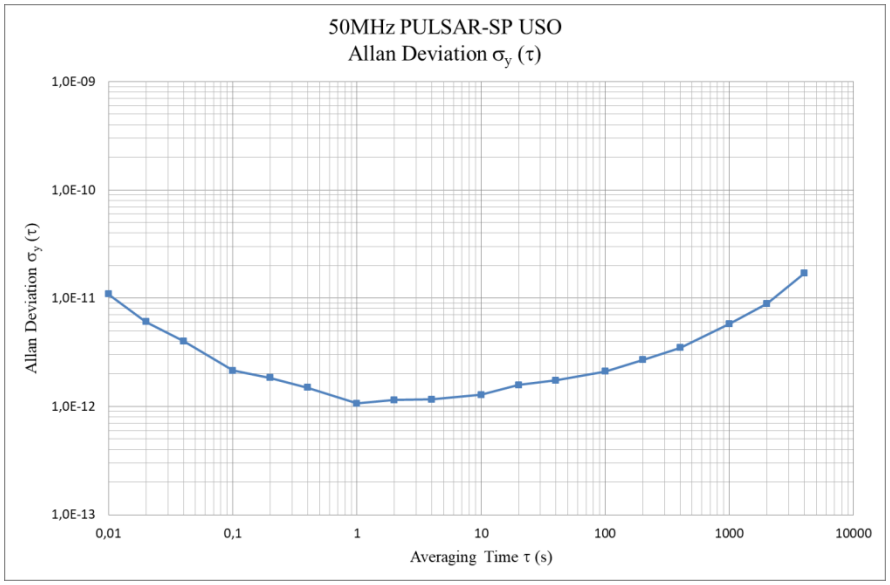

Fig. 7. Short-Term Stability (Allan Deviation)

Frequency Deviation vs Magnetic Field

Thanks to a dedicated improvement work on the oscillator, the magnetic field sensitivity of the PULSAR-SP has been drastically minimized by a factor 25. The frequency deviation versus magnetic field is now below 5.0 E-12 per Gauss in X and Y axis, as shown in Fig. 8. In Z axis, this sensitivity is around 1.0 E-11 per Gauss.

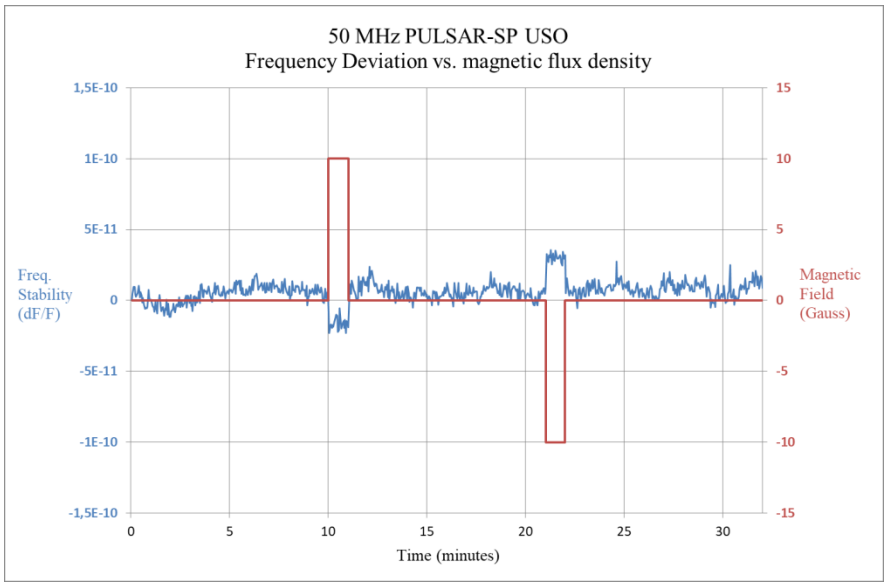

Fig. 8. Frequency Deviation vs Magnetic Field, ± 10 Gauss, X axis

QM QUALIFICATION

A full qualification program has been performed on QM's. The product has been screened and fully tested according to MIL-PRF-55310 standard in Group A and Group B. Then, the qualification (Group C) has been performed on the oscillator, as described in the table 1.

Table 1. Qualification tests sequence

Rep.	Test	Specification	Conditions	Result
1	Vibration (random)	MIL-STD 202, M 214, Cond I D	11,95 g rms, 3 axis, 3 min./ axis	PASS
2	Shock	MIL-STD-202 method 213 with changes, see "Conditions" column	Half-sine 600g; 0,2ms; 3 shock/dir. Total: 18 shocks	PASS
3	Life test	MIL-STD-883, Test Method 1005	1000H. Atm. pressure; +60°C	PASS
4	Thermal shock	ECSS-Q-ST-70-38C §14.6	-55°C/+100°C; 200 cycles	PASS

After each qualification step, basic verifications by electrical measurements have been done: power consumption, frequency calibration, output power level and harmonics, phase noise.

At the end of the qualification sequence, a full electrical performances characterization, identical to Group A tests, has been performed and compared to the initial results. The tests results analysis shows no significant degradations of performances after qualification. All of the electrical characteristics stay within the specification.

Electromagnetic interference emission and susceptibility

The 50 MHz PULSAR-SP has been tested for electromagnetic interference (EMI) emission and susceptibility. The oscillator has successfully passed the EMI tests listed in the table 2.

Table 2. EMI tests sequence

Rep.	EMI Test	Conditions	Result
1	Radiated susceptibility, magnetic field	X, Y and Z axis, Magnetic field level : - 30Hz to 500Hz : 160 dBpT - 1kHz : 155 dBpT - 10kHz : 136 dBpT - 100KHz : 116 dBpT	No susceptibility detected during test.
2	Conducted susceptibility on power line, common mode	Range : 10kHz to 100MHz, Level : 10mA	No susceptibility above -95 dBc detected during test except at 40MHz, 4mA (< -90dBc)
3	Conducted susceptibility on power line, differential mode at the resonance frequency	At resonance frequency of 1.8MHz Level : 0 to 10mA	No susceptibility above -95 dBc detected during test.
4	Magnetic moment measurement	Measurement after degaussing	Magnetic moment : USO with DC supply: 0,18 mA/m² USO without DC supply: 0,603 mA/m²

The fig. 9 shows the superposition of the 50 MHz oscillator phase noise measurements for each test frequency during the Conducted susceptibility (CS) test on power line in common mode at 10 mA level in the frequency range [100 kHz; 900 kHz].

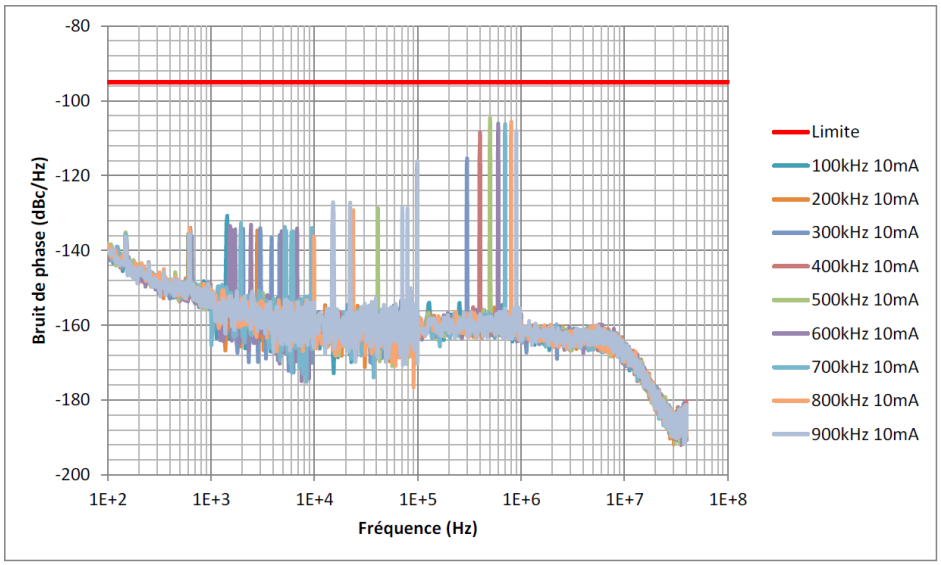

Fig. 9. Phase noise measurement for CS test on power line, common mode

EXTENDED FREQUENCY RANGE VERSIONS

As a first step, ARE has focused his work on the 50 MHz OCXO version. Then, after completing the design, manufacturing and qualification of the 50 MHz version, ARE has developed and tested two additional versions at 10 MHz and 120 MHz output frequencies in order to extend the frequency range of the PULSAR-SP family.

Some demonstrator oscillators have been designed, built and tested. They show the opportunities of the PULSAR-SP family in terms of frequency range.

10 MHz OCXO Version

The oscillator is tuned at 10MHz and uses an ARE SC cut overtone crystal resonator at 10 MHz.

The Fig. 10 shows the frequency stability versus temperature of the 10 MHz USO version in the range [+20°C; +70°C]. The frequency stability is around 1.0 E-9 peak to peak.

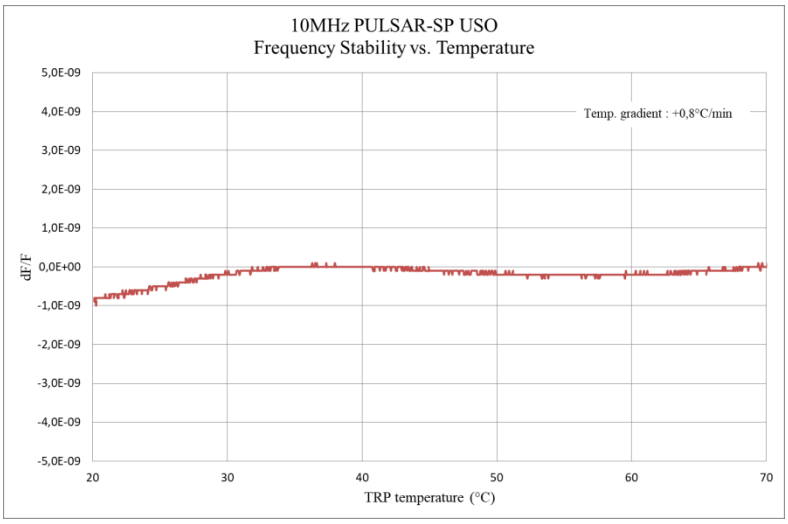

Fig. 10. Frequency stability vs. temperature of the 10 MHz version

The Fig. 11 shows the phase noise measurement of the 10 MHz USO version.

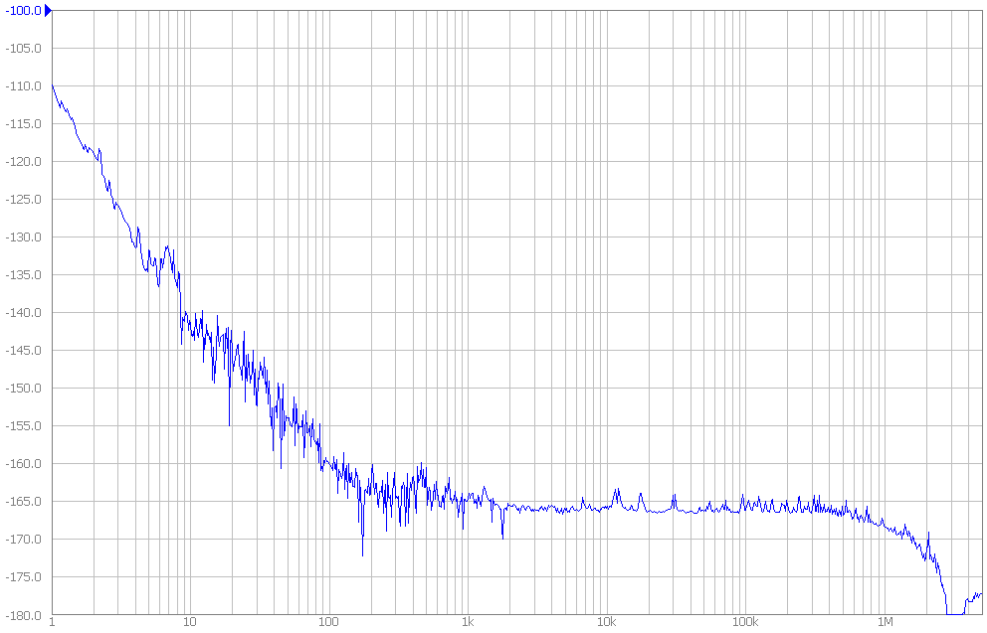

Fig. 11. Phase noise of the 10 MHz version of PULSAR-SP family

120 MHz OCXO Version, direct frequency

The Fig. 12 shows the phase noise measurement of the 120 MHz USO version. The oscillator is set-up in its direct frequency version and is designed with an ARE overtone SC-Cut crystal resonator at 120 MHz.

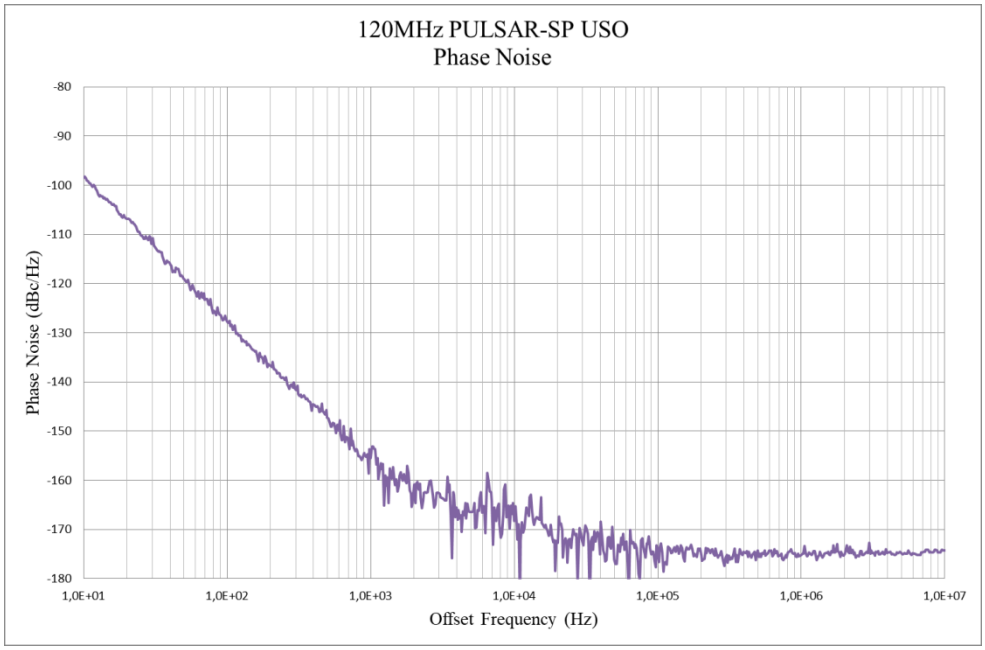

Fig. 12. Phase noise of the 120 MHz version of the PULSAR-SP family

CONCLUSION

ARE has developed a full class S 50MHz reference oscillator for space applications that combines low phase noise and high stability, especially low Allan Deviation. The high Q crystal resonator manufactures by ARE guarantees low acceleration sensitivity, low aging and low close-in phase noise. A dedicated improvement work has been done in order to reduce the magnetic sensitivity of the oscillator. The thermal design gives to the product a high frequency stability versus temperature of a couple of ppb in the operating range.

PULSAR-SP USO performances meet the new technical requirements for earth observation satellites and solar system exploration. This oscillator for space applications has been fully qualified by the CNES from technical point of view as well as product assurance.

Additional versions at 10 MHz and 120 MHz show potential applications of the PULSAR-SP family in terms of frequency range.

To go further on this project, experimental radiation tests in partnership with the French space agency (CNES) are presently in progress. The low dose rate test, TID and Heavy Ions test will be performed until the end of 2018.