Noise measurements of 10 MHz LGT crystal Oscillators

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***Abstract*— our aim is to estimate the potential of LGT resonators to built oscillators of good stability in the short term domain. This objective needs two conditions:**

1) The manufacturing of high Q-factor resonators with a process similar to that used for high stability quartz crystal resonators. 2) The realization of a scheme of an oven controlled oscillator specifically designed for these resonators.

A batch of langatate (LGT) crystal resonators has been manufactured in our laboratory. A satisfying machining and polishing process is now ready. These resonators are optimized in terms of curvature radius and electrode diameter. They are available in an electrode-deposited version as well as in the electrodeless version, the so-called BVA structure.

The energy trapping should still be optimized but here and now good quality factors, closed to 1.4 10^6, are achieved for 10 MHz, 5th overtone resonators.

Presently, their motional parameters are quite different from those of quartz crystal resonators. Classic topologies of quartz crystal oscillators are not well suited for LGT crystal resonators. Further, the high thermal sensitivity of LGT crystal resonators (parabolic f-T curve) requires a particular attention on the oven thermal stability. As a consequence, a specific oscillator topology has been designed for an appropriate use of these LGT crystal resonators.

Resulting frequency stabilities are described in terms of Allan variance or power spectral density of frequency fluctuations.

I. INTRODUCTION

Until now, LGS and LGT crystal resonators have been qualified in term of quality factor, temperature effect, isochronism defect and quality of material. Quality factors of LGT crystal resonators are promising [1, 2, 3] and could be good candidates for ultra stable oscillators, more than LGS crystal resonators. Indeed, their quality factors could be greater than those of high quality quartz crystal resonators [1]: typically, more than 1.10^6 at 10 MHz and short term stability close to $\sigma_y(\tau) = 1.10^{-13}$ ($\tau = 1$ s). A research program has been initiated in order to optimize the machining process of such resonators at 10 MHz. The second objective of this work is to evaluate the short term stability of oscillators equipped with LGT crystal resonators.

Measurements presented below are the first results of a work still in progress. Improvements are still needed.

II. FIRST PROTOTYPES

A. LGT crystal resonators prototypes

Temperature compensated cuts in LGT crystal have been searched for. No doubly rotated cut better than the Y-cut has been found. Unfortunately, the Y-cut exhibits a frequency-temperature curve which is no more than a parabolic one.

The resonator definition has been performed from theoretical calculus and simulation based on the Tiersten theory. The selected configuration is a 10 MHz Y-cut, with a thickness of 0.68 mm, electrode diameter of 3 to 4 mm and working on its 5^{th} overtone (OT). Its expected parameters are: motional resistance R = 36 Ω, parallel capacitor C_0 = 4 pF and Q-factor = 1.10^6.

In practice, the results are different. In fact, theory has to be refund in the case of LGT crystals. Then, optimization of the radius curvature has been performed experimentally (Fig. 1).

All our resonators were made with the same process and manufacturing details are given in [4]. Today four prototypes are usable:

- Two samples without bridges, with electrodes diameter of 8 mm (Fig. 1 and Tab. I), so-called standard structure.

- Two samples with bridges, with electrodes diameter of 3.5 mm (Fig. 2 and Tab. II). In such BVA structure, the bridges (positioned in a zero-force sensitivity) separate the active part (with a diameter of 10.2 mm) to the dormant support.

The frequency-temperature curve of LGT crystal Y-cut is less favorable than a quartz crystal SC-cut as shown in Fig. 4. The frequency at the turn over temperature is shifted of more than 1 kHz from the frequency at ambient temperature.

In the OCXO version, the temperature control should be developed and realized with many cares.

This work is supported by Delegation Generale pour l'Armement (DGA), France.

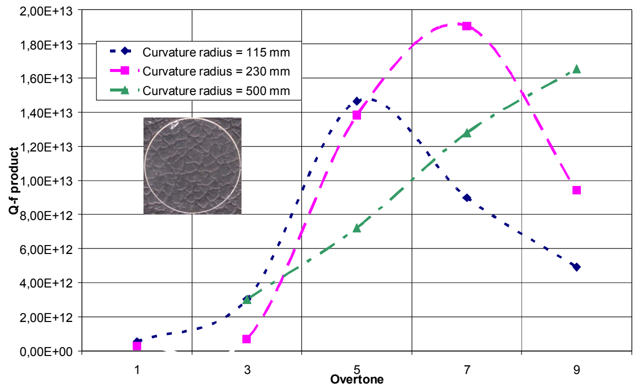

Figure 1. Q-f product (Quality factor × Frequency) versus overtone rank of LGT crystal resonators without bridges with various curvature radius.

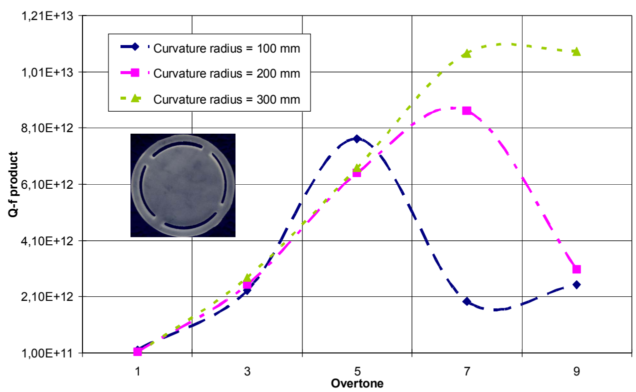

Figure 2. Q-f product (Quality factor × Frequency) versus overtone rank of LGT crystal resonators with bridges with various curvature radius.

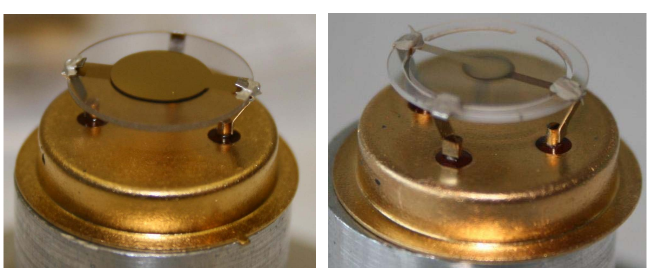

Figure 3. Resonator on its base plate without bridges (left) and with bridges (right)

TABLE I. PLANO-CONVEX RESONATORS PARAMETERS (WITHOUT BRIDGES)

OT	1 (2 MHz)	3 (6 MHz)	5 (10MHz)
R#1 Curvature radius = 115 mm, C0 = 17 pF			
R (Ω)	1.7	11.7	7.8
Q-factor	259 814	484 352	1 407 569
R#2 Curvature radius = 230 mm, C_0 = 18 pF			
R (Ω)	2.7	3.7	5.7
Q-factor	136 356	115 978	1 381 794

TABLE II. PLANO-CONVEX RESONATORS PARAMETERS (WITH BRIDGES)

OT	1 (2 MHz)	3 (6 MHz)	5 (10MHz)
R#3 Curvature radius = 100 mm, C_0 = 9 pF			
R (Ω)	52	13.1	10.6
Q-factor	23 000	427 588	1 113 460
R#4 Curvature radius = 100 mm, C_0 = 9 pF			
R (Ω)	53.7	15.3	16.2
Q-factor	21 476	373 750	759 072

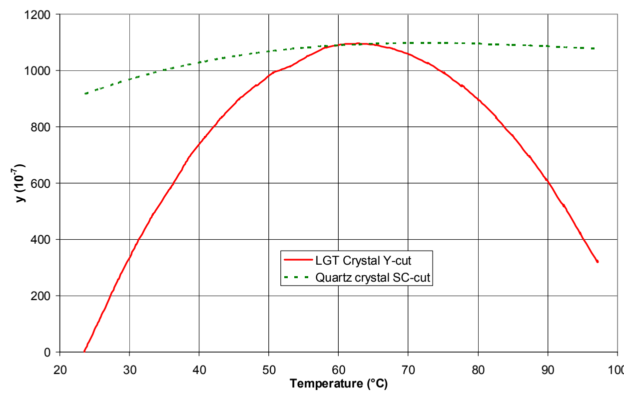

Figure 4. Frequency-temperature effect of LGT crystal resonator compared with that of a quartz crystal SC-cut

B. *Sustaining electronics*

First designs have been developed with resonator R#1 and R#2 (Tab. I & II) for maximizing their loaded Q-factors. The main difficulty is the low motional resistance of the LGT crystal: 10 times lower than quartz crystal resonators (Tab. III). The conventional Colpitts has been adapted to accept a very low resonator resistance which needs a high current biasing. Fig. 5 shows a sketch with two parallel junction field effect transistors (JFETs) which provides a higher source current solution and so, reduces the output impedance of the transistor stage. Moreover, its high input impedance improved the loaded Q-factor.

Barkhausen conditions are completed: this sustaining amplifier saves more than 85% of the unloaded Q-factor (Fig. 6).

Nevertheless, because of the low motional resistances of the 1st and 3rd overtones, oscillator inevitably starts on a lower overtone than the expected one. To run on the 5th overtone, a selective function is needed at the risk of decreasing the loaded Q-factor. Note that the resistance ratio, between two overtone ranks, is much more disadvantageous in the case of our LGT crystal resonator than for the quartz crystal resonator.

TABLE III. QUARTZ CRYSTAL RESONATOR VS LGT CRYSTAL RESONATOR

	Quartz Crystal SC-cut (Improved since 1935)			LGT Crystal Y-cut (Studied since less than 20 years)		
OT	1	3 (10 MHz) optimized	5	1	3	5 (10 MHz) optimized
R (Ω)	476	92	368	52	13	11
C_0 (pF)	3			10		
f (MHz)	3.3	10	16.6	2	6	10
Q (10^6)	0.1	1.3	0.5	0.02	0.4	1.1

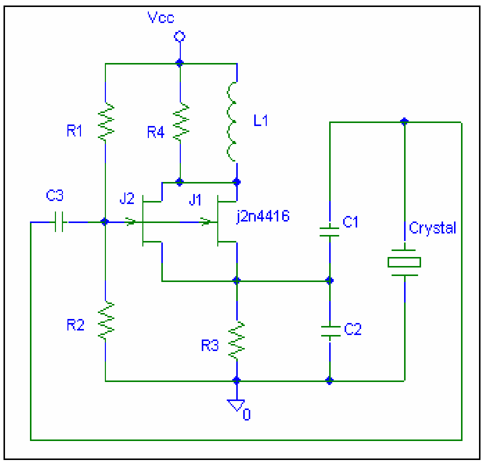

Figure 5. A JFET Colpitts oscillator authorizing high current biasing

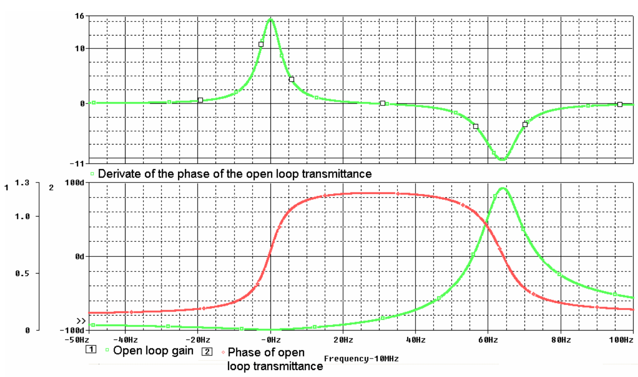

Figure 6. JFET Colpitts simulation results in open loop and loaded on itself

III. CURRENT TESTED DEVICES

A. LGT crystal resonator

For a first test, we chose to use the resonator R#3. It presents a lower motional resistance on the interesting overtone (5th) at 10.2 MHz. Moreover, its electrodes are the smaller ones (Ø 3.5 mm), which gives C_0 close to 10 pF (instead of 18 pF with 8 mm electrodes diameter).

B. Sustaining electronics

To preserve starting on unwanted overtones, the oscillator topology contains a selective filter L1 and C2 (Fig. 7). This implies an unavoidable decreasing of the 5th overtone Q-factor.

The overall electronics is temperature-controlled in a set up environment. Its core including the resonator and its sustaining amplifier is finely regulated. An external copper housing, roughly temperature-controlled, surrounds the previous system (Fig. 8).

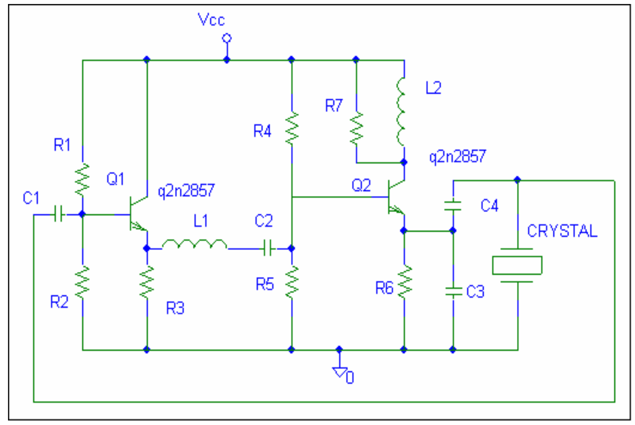

Figure 7. Test oscillator schematic

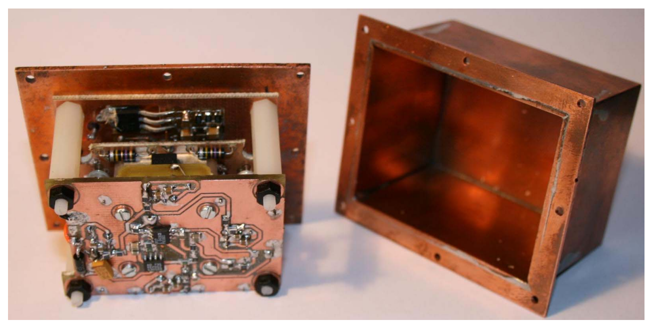

Figure 8. The oscillator under test in a temperature-controlled set-up, with its two ovens inside a copper box surrounded by insulated foam.

IV. NOISE MEASUREMENTS

The available resonator has resonant frequency at 10.2 MHz. The oscillator builds up around this resonator has been compared with a 10 MHz quartz crystal reference (no 10.2 MHz reference was available in the lab for the moment). As a consequence, only Allan deviation measurements have been performed (Fig. 9).

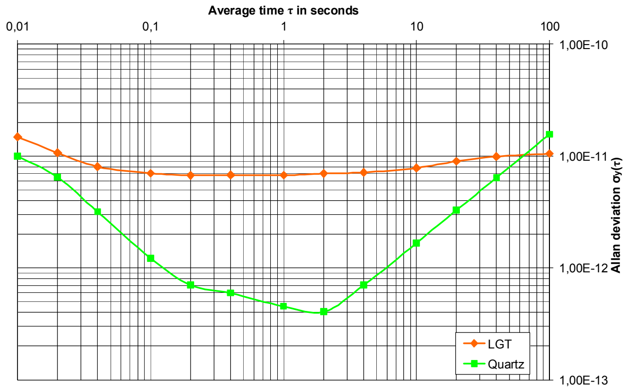

Figure 9. Allan deviation measurement

V. CONCLUSION

Preliminary results are quite poor at this level of our work. They could be better after a few improvements.

- Investigations on LGS and LGT from various suppliers show a large disparity of material quality. We have to find high quality crystals.
- The results above prove that theory adapted for quartz crystal is not directly transposable to LGT. Particularly, the method of energy trapping calculation must be corrected.
- The tested oscillator is very simplified and far from being optimized. A lot of work has still to be done.
- The thermal aspect is predominant and not favorable for ultra stable applications. A high quality temperature control is absolutely necessary.

Anyway, quartz crystal resonators and their associated oscillators have been improved over more than half a century. Langasite-family crystals are studied from less than 20 years. As a consequence, preliminary results described above, must be considered as results of an immature research path.

Capability of LGT crystal oscillator for ultra-stable applications cannot be judged yet from present results.

ACKNOWLEDGMENT

The results reported here are due to the efforts of a number of staff members in the chronometry, electronic and piezoelectricity department of the FEMTO-ST institute, whom the authors are pleased to acknowledge.

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