Optimization of Drive-Level in High Stability Low-Noise OCXOs

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Abstract.

The paper describes results of experimental study of influence of driving current on aging rate and noise properties of OCXOs based on SC-cut 3d overtone crystals. During the study two groups of 12 and 30 samples were tested under different condition: first at driving current raised step-by-step from 1.5 up to 3.0 mA, second at 3.0 mA sustained constant during the experiment. It was not revealed noticeable impact on aging of driving current up to 2.5 mA while 3.0 mA current degraded aging for most units. Phase noise level at close-to-the carrier offset is not sensible to drive level while the noise floor can be reduced to about -170 dBc at 3.0 mA exciting current.

1. Introduction.

Up-to-date communication systems require the lowest level of phase noise of OCXOs as well as high long-term stability (LTS) and short-term frequency stability (STS). Today it's not extraordinary requirement for some OCXO applications to provide simultaneously –170 dBc noise floor, 5E-12 STS and 3E-8/year aging. Furthermore extremely low noise level at high LTS is imperative demand for some low-noise HF OCXOs built on multiplication of low frequency signal.

It is well-known fact that phase-noise in far from the carrier spectrum part is a function of amplitude of current through the quartz crystal. Therefore high level of the crystal excitation is the most simple and effective way of providing low phase noise performance of crystal oscillators. Nevertheless such approach is not easily applicable to high stability OCXOs due to destructive effect of high amplitude vibrations on their aging.

It was observed in even early researches that extremely high driving current can lead to degradation of electrical parameters of the crystals and even destroy them. A number of later works describe influence of driving current on aging of crystal resonators remarking essential advantages of “electrodeless” designs and stress-compensated (SC) cut resonators [1-5]. However some discrepancies in the obtained results don't allow safe estimations of the highest allowed drive level for the resonators.

STS of OCXOs especially at more than 1 s overage time is proved to originate from the resonator features. So study of the parameter under high driving current is necessary part of the OCXO optimization.

Purpose of the present work was experimental study of influence of driving current on aging rate, STS and phase-noise properties of OCXOs based on SC-cut resonators. Basing on obtained results utmost exciting level admitting low aging rate while providing extremely low phase noise of the oscillators was estimated.

2. Aging rate versus drive level

For experimental study of influence of driving current on the aging rate we tested a group of 12 OCXOs built on the base of 10 MHz 3d overtone SC-cut resonators fabricated with conventional process and packaged in HC37/U vacuum holder. The resonators had above 1E+6 Q-factor and about 1.3 H motional inductance. Prior to putting into the OCXO design the crystals had passed through passive aging at 90°C during about 90 days to reduce contribution of various factors on LTS. Initial drive level was set at 1.5 mA remained constant until aging rate of (2-3) E-10/day was reached for most units. Then driving current was increased to 2.0 mA and kept at such level during 10 days. The same procedure was repeated at 2.5 mA and 3.0 mA after what driving current was reduced to initial level at 1.5 mA.

Results of the tests are depicted in fig.1 and table 1. Statistical treatment of the experimental data as distributions of tested units over the aging rates is depicted in fig. 2

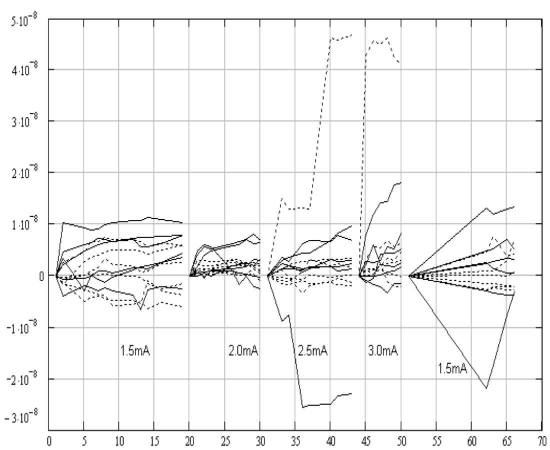
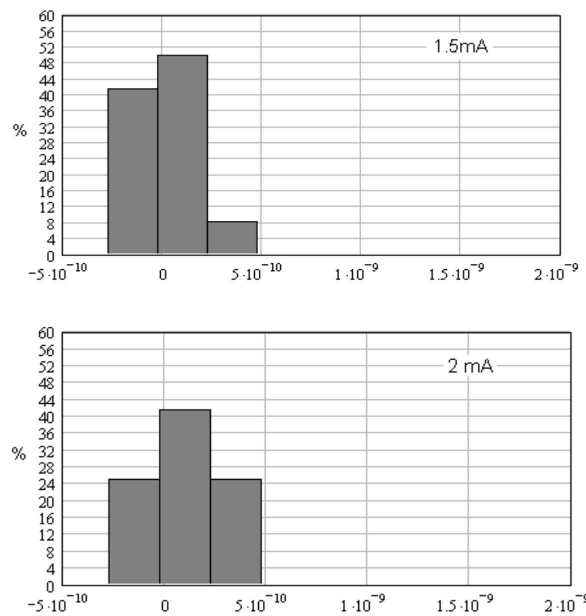


Fig. 1. Aging of 10 MHz SC-cut OCXOs under different excitation levels.

Table 1. Numerical data of the aging test

N	Aging per day at				
	1.5mA	2.0mA	2.5mA	3mA	1.5mA
1	-1,16E-10	5,94E-11	7,28E-11	6,72E-10	-1,41E-10
2	-5,94E-11	8,46E-11	1,04E-11	3,78E-10	1,40E-10
3	2,41E-10	3,29E-10	7,35E-10	1,11E-09	2,14E-10
4	1,53E-10	8,83E-11	2,24E-10	-5,41E-10	7,52E-10
5	7,69E-11	-3,65E-11	2,95E-10	1,97E-10	8,60E-11
6	-1,26E-10	3,58E-11	-1,21E-10	-1,03E-10	-5,00E-12
7	4,42E-10	2,72E-10	1,90E-10	1,15E-09	4,76E-09
8	-6,63E-12	-2,63E-11	-3,38E-11	-4,24E-10	-4,57E-10
9	1,12E-10	3,01E-10	9,22E-11	-1,38E-10	2,24E-10
10	-1,77E-11	-1,87E-10	-8,85E-11	4,71E-10	-2,00E-10
11	9,94E-11	-1,01E-09	3,87E-10	1,56E-09	1,24E-10
12	7,55E-11	2,36E-10	1,26E-10	-3,30E-10	-2,54E-10

As it follows from the data increase of driving current up to 2.5 mA does not cause essential degradation of LTS while all the samples show different sensitivity to the factor. The aging rate of 5E-10 was reached with all the units after 30 days of operation while half of them exhibited about 1E-10/day drift.



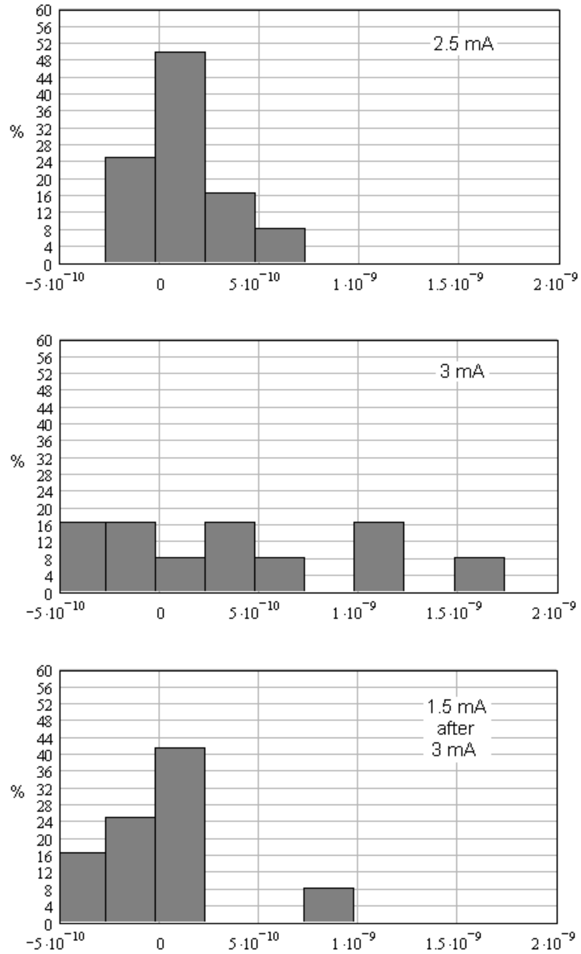


Fig.2. Statistical treatment of the aging data at different driving level.

At the same time increase of driving current up to 3 mA causes noticeable degradation of LTS for the most units to the rate of (5-15) E-10/day. Meantime about 20% of the units remained 1-2 E-10/day rate. As it follows from table 1 sign of aging rate changes versus drive level can be positive or negative while some samples indicated reverse of the sign during the run at some current values.

As it follows from the data restoring initial drive level of 1.5 mA has reduced the aging rate to about initial values that obviously denies hysteresis character of the high drive level factor of aging.

For more detailed evaluation of aging rate under high driving current we've tested another group of 30 pcs similar OCXOs excited permanently by 3 mA current. Fig. 3 displays typical behavior of the units, statistical treatment of the aging data after 30 days of operation is depicted in fig.4.

As one can see from the data there is no significant difference in LTS distributions between both groups excited at 3.0 mA that confirms above conclusions and negates difference of the aging behavior under high drive level permanently sustained and gradually set by a few steps.

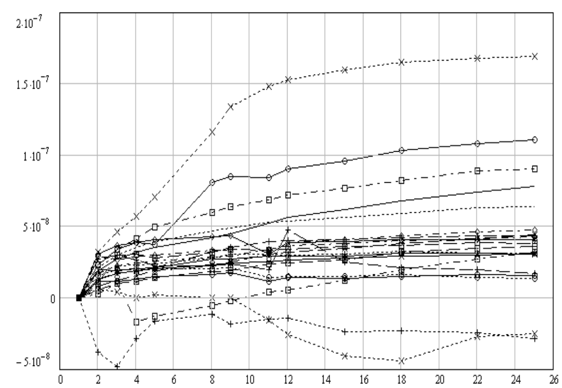


Fig. 3. Aging of OCXOs excited permanently by 3.0 mA current.

On the basis of the present study as well as on other researches one can deduce physical mechanism of influence of the driving current on the aging rate.

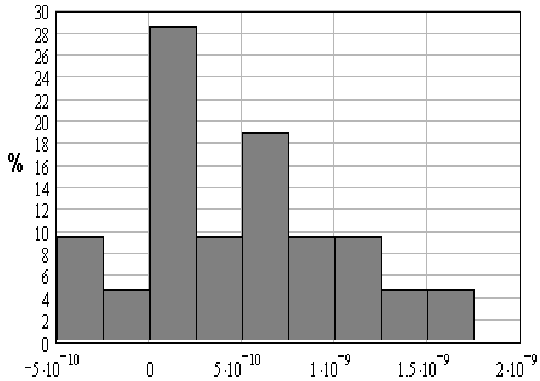


Fig. 4. Statistical treatment of the aging data at 3.0 mA driving current after 30 days operation.

It was revealed in [6, 7] that influence of driving current on aging rate of stress-compensated SC-cut crystals is much weaker than that of AT cut crystals that allows presumption of the film electrode stress relaxation as most probable mechanism of the influence. Such assumption is supported by very low sensitivity to drive level of aging rate of "electrodeless" BVA designs built on AT-cut crystals.

Above results should exclude from likely aging factors of stress relaxation in the quartz material and in the crystal mounting structure, the later besides due to radically decayed vibration amplitude at the crystal edges.

At last, the present researches indicating alternative sign of the aging versus driving current for different samples exclude the mass transmission factor in the resonator volume that would have brought on only positive changes of frequency at high drive level.

Summarizing all considered above one can conclude that relaxation of the electrodes stresses under high vibrations amplitude is most probable cause of the aging factor.

Different sign of the drift for the tested samples can be obviously explained by different sign of initial electrode stresses in vibration displacement direction. Since the stresses pattern originates from the base plating process the stress-less deposition procedure can be a method of improvement of LTS under high drive level that however should be a subject of further investigations.

3. Phase noise and STS versus drive level

It's common knowledge that phase noise level of a crystal oscillator in 1/f and "floor" parts of the spectrum is in inverse proportion to the oscillation amplitude, and consequently, to driving current through the crystal resonator.

Influence of the driving current on STS and phase noise in close-to-the currier region has not been revealed except through variation of Q-factor due to non-linear coupling with spurious modes. Nevertheless excitation at extra high level requires additional study of the influence.

We've tested the phase noise behavior in 1 Hz to 10 kHz offset at driving current varied from 1.5 mA to 3.0 mA. Results of the measurements for three samples are depicted in fig 5.

As it follows from the data increase of the current up to 3.0 mA doesn't impact noticeable on phase noise in close to the currier region. Meantime phase noise at above 100 Hz offset drops with the current raise reaching about –165 dBc "floor" noise at 2.5 mA and –170 dBc at 3.0 current.

Allan variance measured under different current values (fig.6) has not revealed any dependence on the drive level that proceeds from different mechanism of influence of driving current on STS and LTS.

Extremely low phase noise accomplished at 2.5-3.0 mA current can be a good basis for multiplication of the signal. Fig. 7 depicts phase noise spectrum of 30 MHz OCXOs built on tripling the 10 MHz signal. As one can see about –160 dBc "floor" is provided with 3.0 mA current that along with about 5E-12/1s Allan variance and low aging rate being property of 10 MHz SC-cut crystal OCXO design is an attractive option for a variety of low noise HF applications

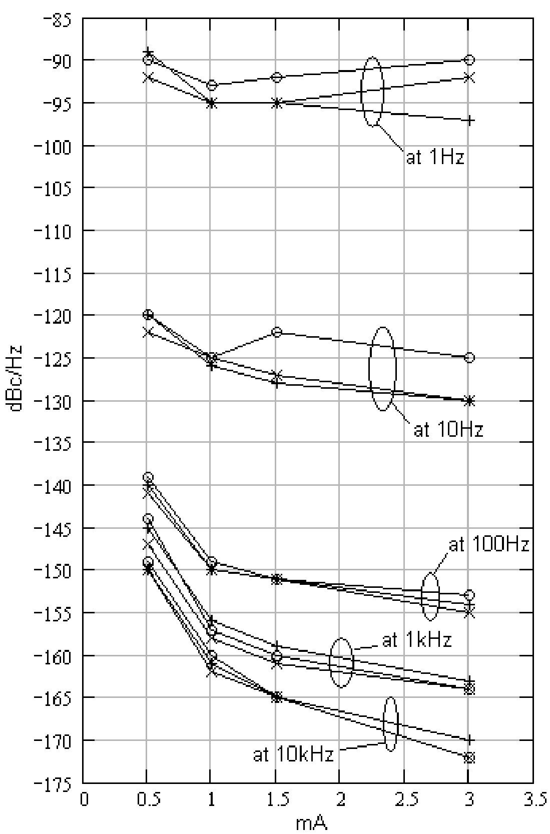


Fig 5. Phase-noise vs. drive level for 3 OCXO samples.

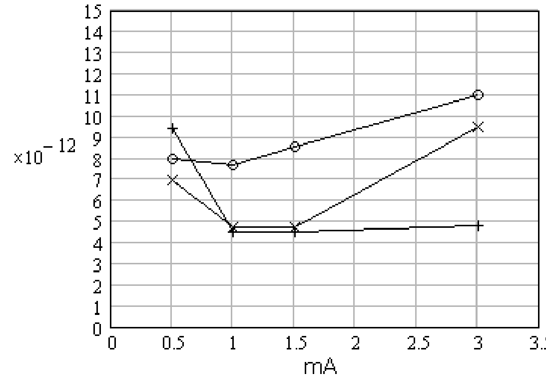


Fig 6. Allan variance (1s overage time) of OCXOs under various current values.

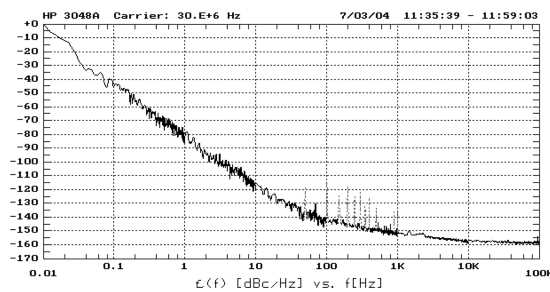


Fig. 7. Typical phase noise of 30 MHz OCXOs built on tripling 10 MHz signal at 3.0 mA driving current.

Conclusion.

1. Aging rate of OCXOs based on 10 MHz 3d overtone SC-cut resonators shows weak dependence on the drive level at up to 2.5 mA while noticeable aging degradation at above 3.0 mA current. Meantime essential part of the crystals remains excellent aging rate even at 3.0 mA current.

2. Most probable mechanism of the aging degradation is relaxation of electrode stresses originated from the deposition process. Therefore optimization of procedure may be a

way of improvement of LTS at high drive levels.

3. Phase noise of OCXOs doesn't depend on drive level at close-to-the currier region while can be improved significantly at more offset reaching at 3 mA current below –170 dBc "floor" noise

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