Activity Dips In Standard Oscillator

Laurent Toudret(1), Laurence Cosqueric(2), Bernard Sanctorum(3), *Nicolas Gufflet*(4)

(1)Astrium SAS, 1 boulevard Jean Moulin, CS 30503
78990 Elancourt Cedex, France
laurent.toudret@astrium.eads.net

(2)Astrium SAS, 31 rue des Cosmonautes, Z.I. du Palays
31402 Toulouse Cedex 4, France
laurence.cosqueric@astrium.eads.net

(3)Astrium SAS, 1 boulevard Jean Moulin, CS 30503
78990 Elancourt Cedex, France
bernard.sanctorum@astrium.eads.net

(4)Rakon France SAS, 44 avenue de la Glacière
95100 Argenteuil, France
nicolas.gufflet@rakon.com

INTRODUCTION

Activity dips in crystals can induce slight changes in the resistance- and frequency-temperature curve around particular temperature. In order to get a better understanding of the behaviour, we characterized a standard oscillator circuitry on different PCBs using different crystals, by measurements with small temperature steps. The tests include operating-life tests.

ACTIVITY-DIP ORIGIN AND BEHAVIOURS

An activity dip is a sharp increase in the equivalent series resistance of the crystal which can occur at a specific temperature (Fig. 1) [1] [2] [3] [4]. The activity dip is accompanied by a deviation of the frequency versus temperature characteristic from a smooth curve (Fig. 1), but this is often much less pronounced than the resistance increase. Activity-dips are typically caused by the coupling of the main mode (usually thickness shear resonance) with other modes (e.g. high overtone flexure or extensional modes). When the frequency of the interfering mode coincides with the frequency of the main mode, energy is lost from the main mode and an activity dip occurs. This process can also appear if the interfering mode is not piezo-electrically excitable, i.e. very often the parasite mode can only be seen when it interferes with the main mode. In the case of flexure or extensional modes the frequency of a mode causing an activity dip depends upon lateral dimensions; consequently, activity dips are sensitive to small dimensional changes, which may make their control difficult. In some cases, especially at high drive level, the coupling can occur because of the coincidence of a harmonic of the main mode with an other higher resonance mode. The nonlinear behaviour at high drive level can also permit the transfer of energy to another mode due to a nonlinear coupling [5] [6].

In any case there is no theory with sufficient accuracy for design, which leads to reliance on empirical methods [7] [8].
The activity-dips are strongly influenced by load reactance. Indeed the activity-dip temperature is a function of load capacitance because the interfering mode’s frequency usually has a large temperature coefficient and a motion capacitance C_1 that is different from that of the desired mode. Similar signatures can be mixed up, but caused by processing problems, e.g. loose contacts. But such dips usually change with temperature cycling, rather than with load capacitance. They can be drastically reduced by proper design of the crystal.
SC-cut crystals present less activity-dip than the AT-cut which is widely used in standard oscillators. The overtone modes are also less sensitive to activity dips. They are stable over time.

Typical activity dips showing anomalies in the frequency versus temperature and series resistance (Rs) versus temperature characteristics are illustrated in Fig. 2a and Fig. 2b. The curves labelled f_R and R_1 are the frequency versus temperature and series resistance versus temperature without a load capacitor. The f_L and R_L curves are the frequency versus temperature and series resistance versus temperature of the same resonator when load capacitors are in series with the resonator.

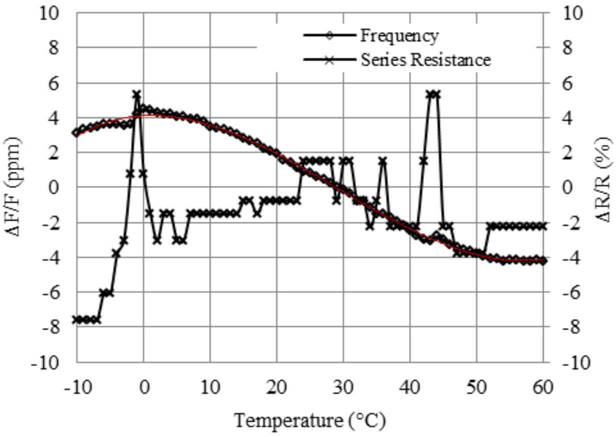


Fig. 1: Relative series-resistance drift and relative frequency drift in temperature of a 13.240MHz AT-Cut crystal

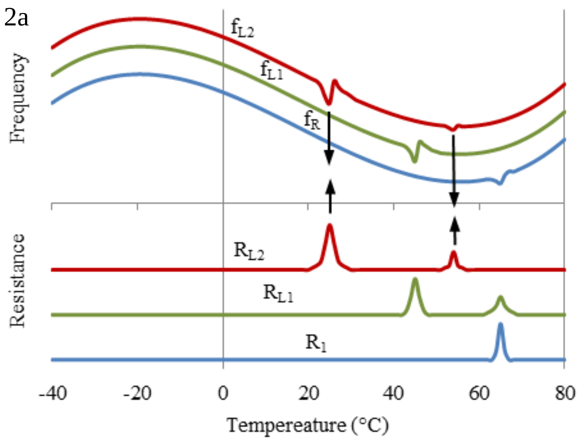


Fig. 2a: Activity dips vs Load Capacitance illustration

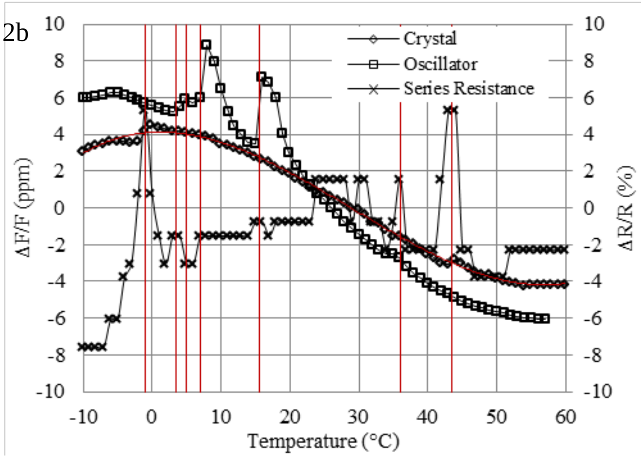


Fig. 2b: Current design, frequency drift for the crystal alone and for the crystal integrated in the oscillator circuitry.

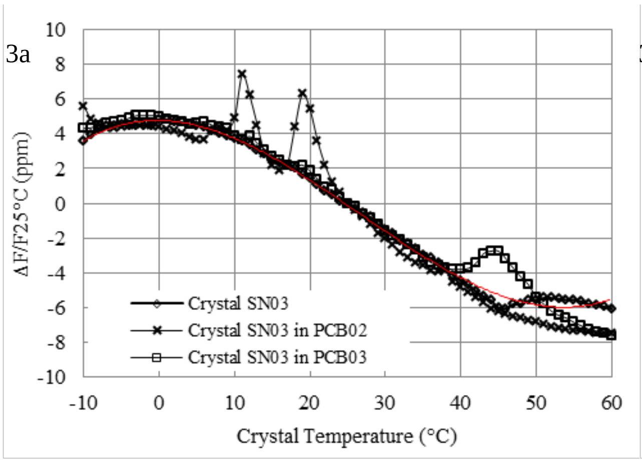
An activity dip can cause intermittent failures. It affects both the frequency and the resistance (i.e. the quality factor Q) of resonators. When the oscillator gain is insufficient, the resistance increase stops the oscillation. For example, the clock in an observation satellite stopped periodically a certain time interval after the satellite entered the earth's shadow. As the satellite cooled, the oscillator's temperature reached the activity dip temperature and the oscillation stopped. Upon further temperature change, the oscillation resumed. Even when the resistance increase is not large enough to stop the oscillation, the frequency change can cause intermittent failures, e.g. a loss of lock in phase-locked systems.

OSCILLATOR CHARACTERIZATION

To improve the overall manufacturing lead-time, we introduced in the control electronic circuit a discrete Pierce-oscillator in replacement of standard crystal oscillator. The lead time of a crystal is half of a standard crystal oscillator. Knowing the possible activity-dip on crystal, we deeply characterized this function, by using two printed-circuit boards (PCB) and two crystals from the same batch [9]. All the crystals were in conformance with their procurement specification: ESCC 3501/019 [10]. We measured the frequency for crystal temperature-steps of 1°C, after waiting for the frequency stabilization.

Printed circuit board and crystal dependency

Firstly, we checked that the drive level is within the manufacturer recommended range.
After checking, we characterized the impact of the oscillator circuitry on the frequency-temperature curve. Comparing the frequency-temperature characteristics of the crystal alone and when mounted in the oscillator, we can confirm that the oscillator circuit has an impact on the frequency-temperature curve characteristics (Fig. 2b). Some under-laying activity-dips are attenuated; on the other hand some of them are activated.
Depending on the printed-circuit board and oscillator discrete components, the frequency-temperature characteristics can largely differ. In the temperature range of -10 to 45°C, the crystal SN03 mounted on PCB03 presents smoother curve than when mounted in PCB02 (Fig. 3a). We characterized a second crystal from the same lot (Fig. 3b): the same conclusion can be applied.
As we did not notice any change on frequency-temperature curve after dismounting and re-mounting of the same crystal on the board, we can confirm these changes are not related to crystal properties changes induced by the mounting – dismounting operation.



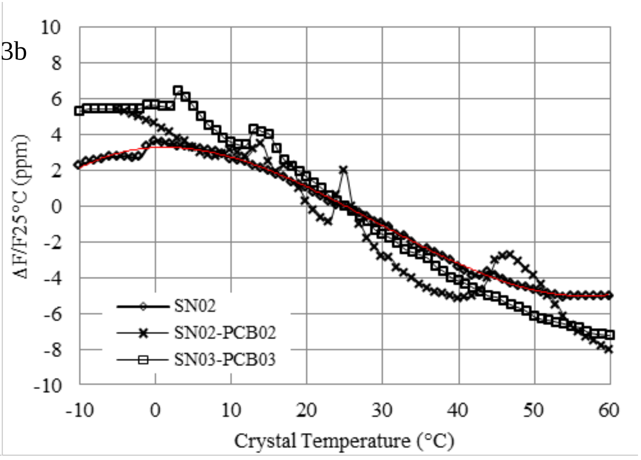


Fig. 3a Serial number 03, as measured by the manufacturer, and mounted respectively in PCB 2 and 3
Fig. 3b Serial number 02, as measured by the manufacturer, and mounted respectively in PCB 2 and 3

Life test results

After the initial characterization, we performed a life-test of 1000h hours at 105°C on the SN03 mounted on the PCB02. As expected, we observed that there was no evolution on the frequency-temperature curve over time (Fig. 4).

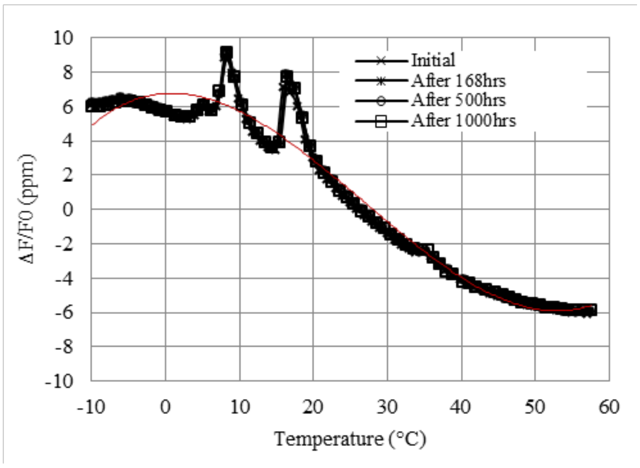


Fig. 4 Operating Life Test Results

STANDARD OSCILLATORS PERFORMANCES

What about standard oscillator performances?
Examples are given from a procurement lot of standard 20MHz crystal oscillator.
The measurements for the group A of the MIL-PRF-55310 are done each 15°C, above & below 25°C in the [-30°C ; +80°C] range. Therefore, it is quite difficult to detect the possible activity-dips. For this particular lot, we requested additional measurements every 0.1°C from -30°C to +80°C (Fig. 5).

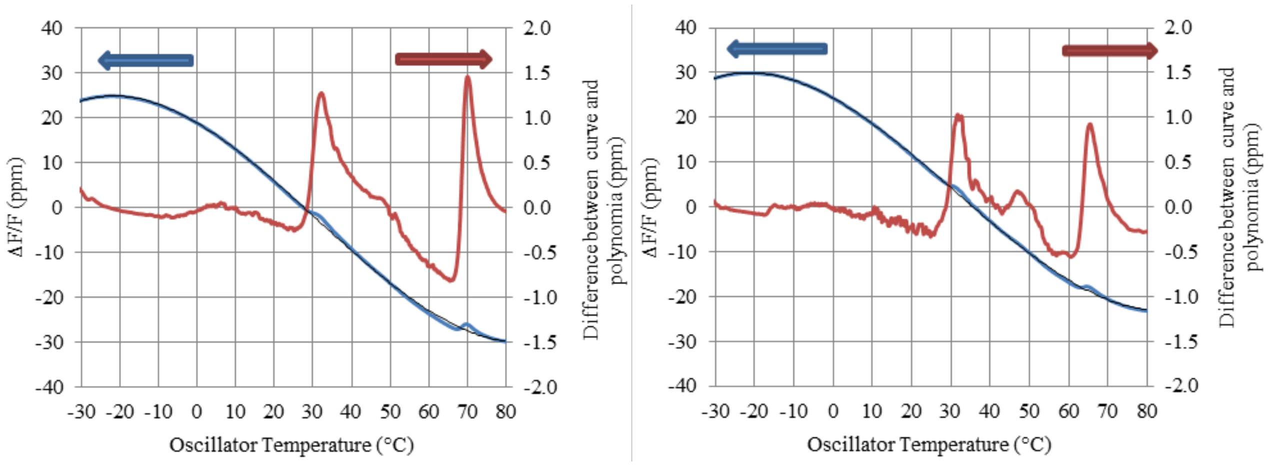


Fig. 5 Examples of Two Oscillators 20MHz from the Same Batch

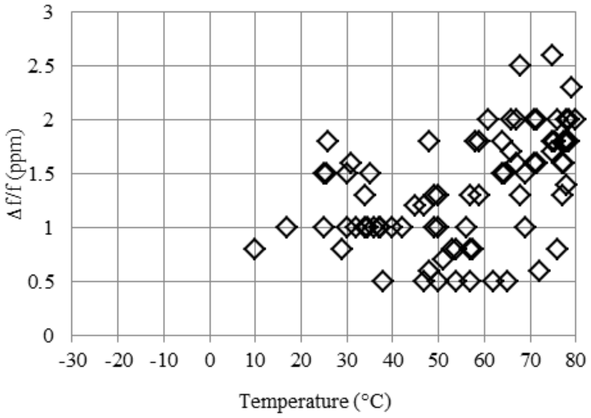


Fig. 6: Distribution of the Activity-dips in ppm peak-to-peak vs.
temperature for a batch of 40 oscillators

The activity-dips are distributed over a large temperature range from +10°C to +80°C (Fig. 6). One oscillator can exhibit two or three of them. The larger ones are positioned around 75°C which is outside the normal operating range. This frequency drift has therefore no impact on our electronic circuitry.

CONCLUSION

The activity dips are inherent to crystal resonators construction; they are typically stronger on low frequency resonator working on fundamental mode. For the same design and lot procurement, these activity-dips differ from one crystal to another and from one complete oscillator circuit to another. The ageing has no impact on the frequency-temperature shapes, i.e. the activity-dips are stable over time.
These changes may not be detected by standard screening procedures or be small enough to be acceptable, but they can be amplified or activated by the other elements of the oscillator circuit.

This phenomenon can be present on standard hybrid XO procured according MIL-PRF-55310, but not detected, due to the standard measurement-steps required: 15°C.

The changes in frequencies slopes are around few ppm/°C and are generally not a concern.

When activity-dips can lead to a dysfunction of the electronic circuitry, the use of AT-cut operating on 3rd or 5th overtone, with an adapted screening procedure (one frequency measurement every degree or less) can be a solution.
A measurement in dummy oscillator can also be a solution on crystal manufacturer side but since it is made unitarily then the measurement cost is higher.

REFERENCES

[1] A. Ballato and R. Tilton, *"Electronic Activity Dip Measurement,"* IEEE Trans. on Instrumentation and Measurement, Vol. IM-27, No. 1, pp. 59-65, March 1978; also *"Ovenless Activity Dip Tester,"* in Proc. 31st Ann. Symp. On Frequency Control, pp. 102-107, 1977.

[2] John R. Vig, *Quartz Crystal Resonators and Oscillators For Frequency Control and Timing Applications*, a Tutorial, November 2008

[3] John R. Vig, *Introduction of Quartz Frequency Standards*, SLCET-TR-92-1 (Rev. 1), Army Research Laboratory, October 1992

[4] Professor Yook-Kong Yong and Professor Ji Wang, *A tutorial at the 2011 Joint Conference of the IEEE International Frequency Control Symposium and the European Frequency & Time Forum*,

[5] C. Franx, "*On Activity-Dips of AT Crystal at High Level of Drive*", 1967

[6] J. Birch and D.A. Weston, "*Frequency/Temperature Activity/Temperature Anomalies in High Frequency Quartz Crystal Units*, 1976

[7] Shih-Yung Pao, Qiao-Qiao Pan and Min-Chiang Chao, *"An Efficient AT-cut Quartz Crystal Resonator Design Tool for Activity Dip in Working Temperature Range"*, Preprint for the 2011 Joint Conference of the IEEE International Frequency Control Symposium & European Frequency and Time Forum, San Francisco, California, USA , May 1-5, 2011

[8] B. Dulmet, "*Finite Element Analysis of Activity-Dips in BAW Resonators and Sensors*", 2002 IEEE International Frequency Control Symposium and PDA Exhibition

[9] Bernard Sanctorum, *Mesure du vieillissement d'un oscillateur Pierce utilisant un quartz Rakon pour Astrix 200*, Technical Report from Astrium, October 2010, unpublished

[10] ESCC, *"Crystal Units in Metal Holder, Based on Type T1507, Frequency Range 2.5 – 50MHz"*, N° 3501/019 Issue 4, November 2010