Space Passive Component Days
ESTEC
Activity Dips In Standard Oscillator

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Introduction

The aim of this presentation is not to have a complete overview of the consequences of activity dips in crystals but to show a concrete example of what can be expected in an oscillator design.

Content

Activity-dips Origin and Behaviors

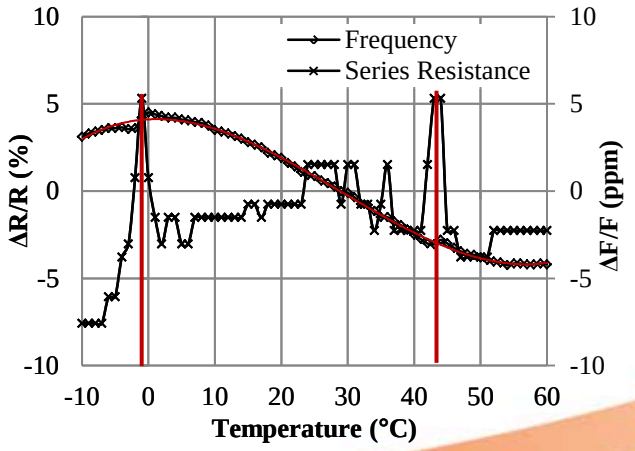
Oscillator Characterization

Standard Oscillator Performances

Conclusion

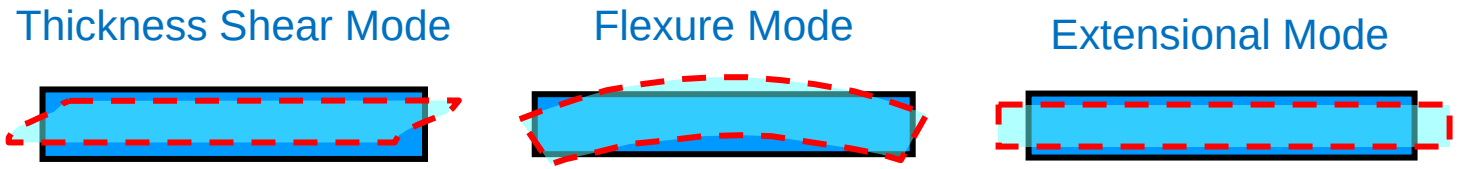
Activity-Dips Origin and Behaviour (1/4)

- What are Activity-dip?
  - They are a sharp increase in the equivalent series resistance of the crystal which can occur at a specific temperature
  - They are accompanied by a deviation of the frequency versus temperature characteristic from a smooth curve



Activity-Dips Origin and Behaviour (2/4)

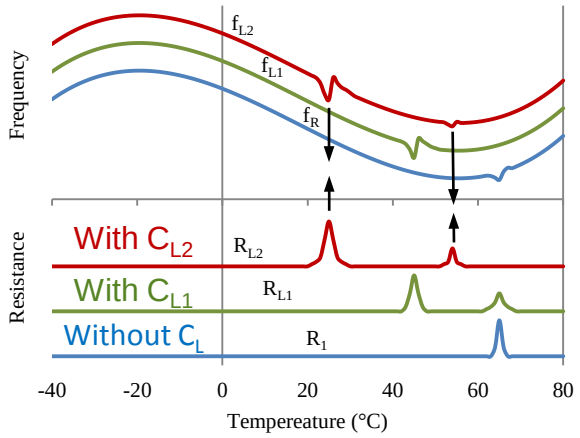
- Origin of Activity-dips
  - Couplings of the main mode (usually thickness shear resonance) with other modes (e.g. high overtone flexure or extensional modes)



  - 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

Activity-Dips Origin and Behaviour (3/4)

- Activity dips behaviour
  - There is no theory with sufficient accuracy for design crystal → empirical methods still used
  - The activity-dips are strongly influenced by load Capacitance
  - They are stable over time.
  - 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



Activity-Dips Origin and Behaviour (4/4)

- Activity dips consequences
  - An activity dip can cause intermittent failures
  - It affects both the frequency and the quality factor Q of resonators with at worst an oscillation stopping
    - 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

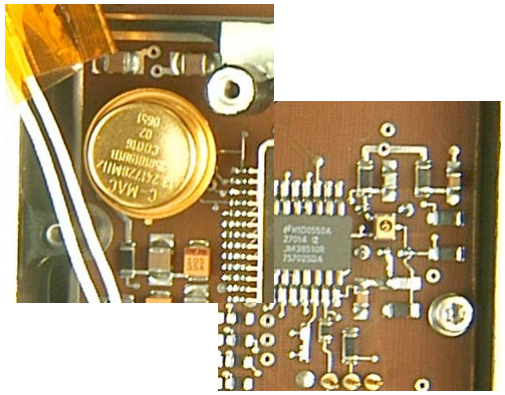
Oscillator Characterization (1/5)

- Context
  - Space equipment for long term mission (up to 15 years)
  - The electronic requirements:
    - Frequency adjustment per electronic channel,
    - Limited difference between the frequency-temperature dependency and a third order polynomial approximation
  - To improve the overall manufacturing lead-time, introduction of a discrete Pierce-oscillator instead of standard XO (gain of 20 weeks)
  - A characterization was done to check the influence of the crystals, the PCBs and time

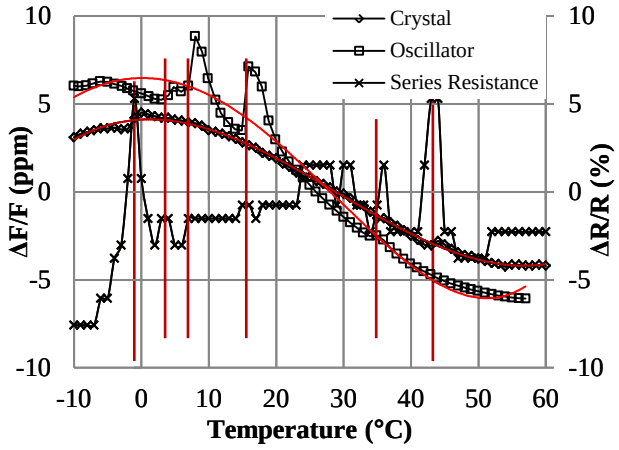
Oscillator Characterization (2/5)

- Printed circuit board and crystal dependency
  - AT-cut Crystal characteristics without load capacitance
  - Crystal characteristics mounted in the oscillator circuit

Recto



Verso

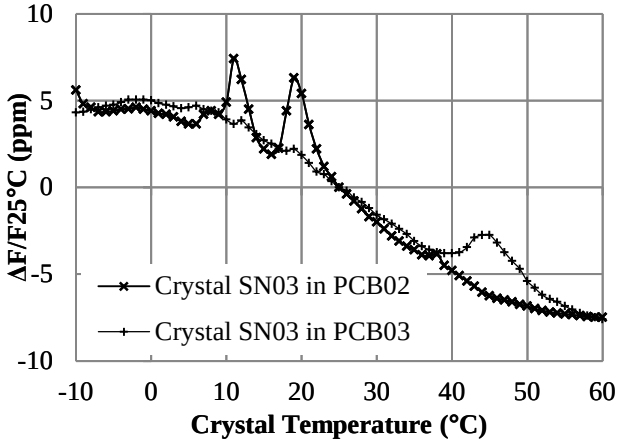


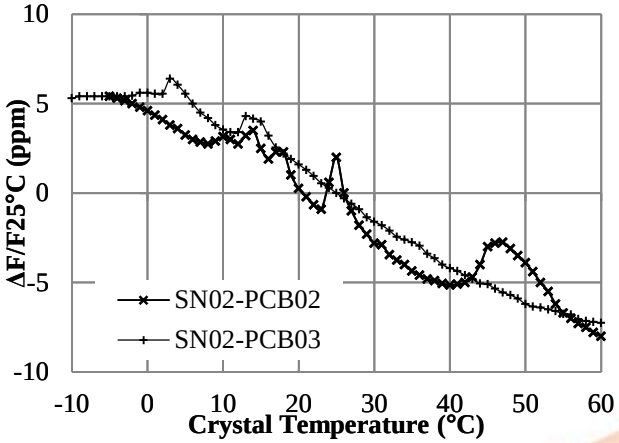
→ As expected, the load capacitance has an influence on the temperature characteristics

→ But no change after dismounting and remounting of the crystal

Oscillator Characterization (3/5)

- Printed circuit board and crystal dependency
  - 2 different PCBs (same list of components and same PCB-layout but from two different manufacturers)
  - A second crystal from the same lot was mounted on the 2 PCBs

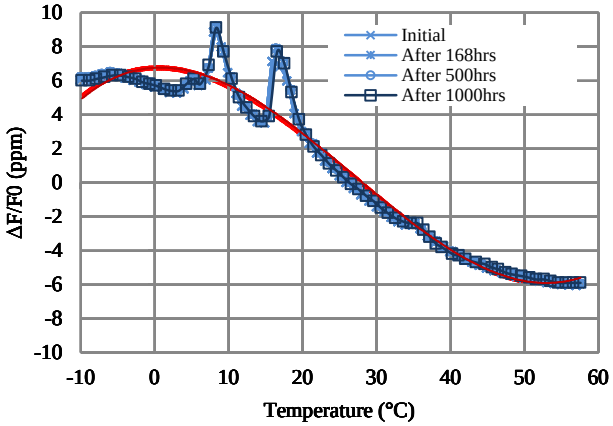




→ Wide interaction between crystals and parasitic elements from the PCBs

Oscillator Characterization (4/5)

- Life test results
  - Conditions: 105°C at crystal case
    - After 168 hours
    - After 500 hours
    - After 1000 hours



→ No consequence on temperature characteristic

Oscillator Characterization (5/5)

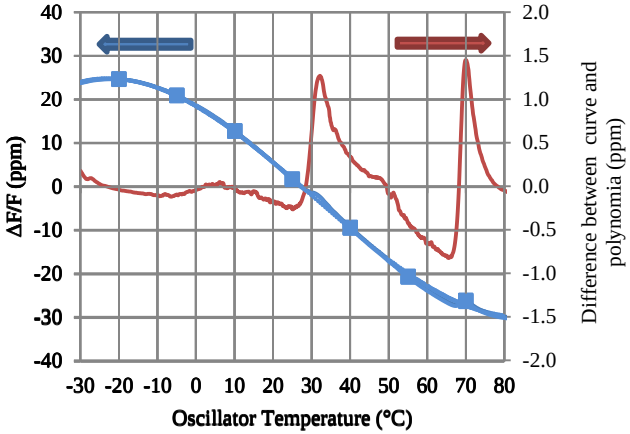
- Conclusion
  - The oscillator characteristics are different from the crystal alone
  - The parasitic elements have an impact on the performances (especially the load capacitance)

  But
  - No oscillation stopping
  - No change with time
  - Mounting has no influence
  - Activity-dips are enough small, no consequence on electronics

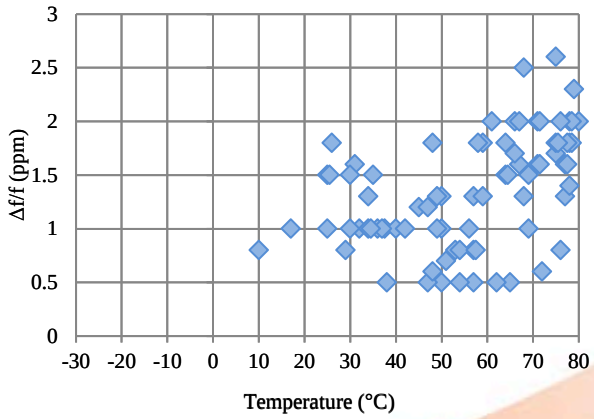
Standard Oscillators Performances

- Standard XO: Batch of 40 parts Class-S MIL-PRF-55310
  - In addition with the std, measurements from -30 to +80°C, step 0.1°C
  - Example of frequency-temperature curve on one oscillator
  - Distribution of activity-dips in ppm peak-to-peak vs the temperature

Measurements Step 0,1° Difference in ppm with 3rd



Distribution



→ With the standard measurements by step of 15°C: no detection

→ The activity dips are widely distributed over the temperature range

Conclusion (1/2)

- Activity dips at crystal level
  - They are inherent to crystal resonators construction
  - They differ from one crystal to another into a batch
- The oscillator characterization confirms that
  - Crystal behavior are sensitive to the external elements (load capacitor)
  - The final frequency-temperature curve can not be predicted
  - The ageing has no impact on the frequency-temperature shapes
- Consequence on Standard XO
  - This phenomenon can be present on standard hybrid XO
  - But not detected, due to the standard measurement-steps of 15°C.

Conclusion (2/2)

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

  But

  - When activity-dips can lead to a dysfunction of the electronic circuitry
    - Use AT-cut operating on 3rd or 5th overtone
    - With an adapted screening procedure
    - Use a dummy oscillator to screen the crystal at the manufacturer could be a solution

- Thank you for your attention
- Any question?

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