FEM thermal analysis of quartz oscillator with COMSOL

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Abstract— **The aim of this paper is to show that commercial software is able to realize an utter thermal analysis of a quartz oscillator. SOLIDWORKS files of the mechanical assembly are simplified and exported into COMSOL. Based on the assumption that under vacuum the heat transfer process is the conduction, material properties and boundary conditions are filled in the different pop-up boxes to solve the conduction equation.**
This paper presents results of modelisation applied to a new design which is developed by TEMEX: a new space OCXO with low consumption and low noise oscillator has been designed with this FEM modelisation.

Introduction

Numerical studies of thermal system by finite elements are a widespread tool to design different types of device. Nevertheless, simulating a whole crystal oscillator was a difficult task, especially because of the PCB which is composed of a lot of details (mass plans, Pads, via…). So far, Lumped model was used to mimic the thermal behavior of the PCB. Different studies [**1**] have shown that the lumped models fail in modelizing the actual thermal field on a PCB with accuracy.
In this paper, we take advantage of the new meshing and importing possibilities brought by **COMSOL** to undertake a complete thermal simulation of the oscillator. We first carry out an accurate local representation of the PCB (copper traces, mass plan) and other parts of the oscillators with the help of **solid work.** A numerical model is then established by importing this geometry onto **COMSOL,** meshing it and filling all the material conductivities and boundary conditions in the dedicated boxes. The results of the simulations allow to forecast the power consumption of the heating transistor and to optimize the layout of the main active components. This procedure was applied to a brand new OCXO (oven compensated crystal oscillator) developed by **TEMEX**.

I. FEM MODEL

A. *Geometry*

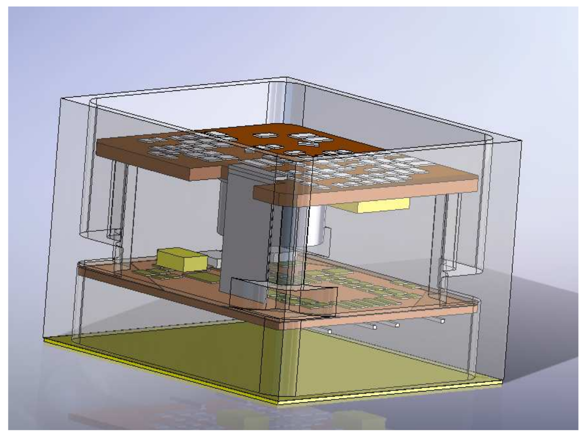

Figure 1 : modelisation (inside of the OCXO)

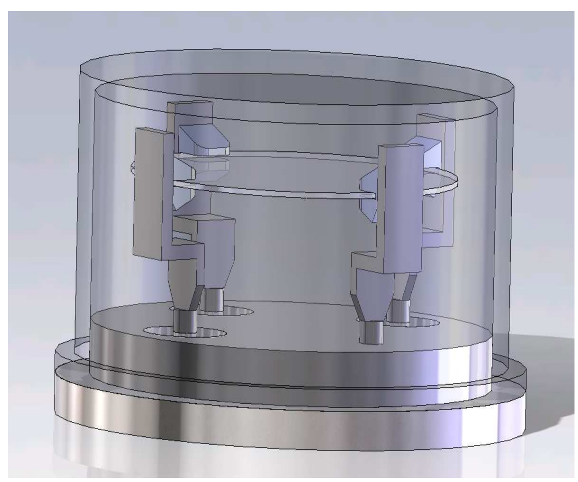

Figure 2: modelisation of the quartz (TO8)

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The geometry was created on solid work. The parts was designed independently and then assembled. The PCBs are represented with a maximal amount of details. Pads and mass plans are integrated to take into account the local concentration of copper. Despite Other parts like flex, connectors, screws and components are simplified with a lumped model; it doesn't affect the accuracy of the simulation like a lack of details on the PCB.

The quartz geometry was independently created. The simplification process consists in removing the metallization and modifying slightly the shape of the quartz leads without impacting heavily on the heat transfert.

B. *Numerical model*

The geometry is imported from the previous **solid work** design into **COMSOL.** The first step is to mesh it. A coarse triangular mesh constitutes a good trade-off between memory requirement and the accuracy of the simulation. Then, based on the assumption that under vacuum the main heat transfer process is the conduction, we solve the heat conduction equation with the bottom set at the outside temperature and the other boundaries insulated. The iterative algorithm (GRMES with algebraic multigrid preconditioner) has been chosen because this is one of the best to solve large size problem requiring less memory than a direct solver.

In order to investigate the quartz temperature map, the temperature at different points corresponding to the quartz leads and coming from the previous simulation are used as entrance data for a modelisation of the sole quartz package.

C. *Adding the PI control*

COMSOL allow to integrate local variable like the temperature and to allocate the value in a global scalar expression. The proportional integral algorithm (1)

$$\mathbf{reg = (Ki^*\textstyle\int(tset\text{-}tsensor)+Kp(tset\text{-}tsensor))} \quad (1)$$

is therefore implemented into **COMSOL** with saturation terms to represent the non-linear behavior of the operational amplificator. Previous simulation has shown that if the non-linear terms weren't taken into account, a wind-up phenomenon would occur. It is a purely numerical problem in our case: the integration doesn't stop when the A.O is saturated and the modulation term stays a long time at it maximum value. The temperature undergoes tremendous oscillations which are not physical. The use of function that shut down the integration when the maximal value of the modulation term is reached (i.e. 1) is the best way to counteract the wind-up numerical instability.

The driven heat released by the transistor is then integrated in the model by the mean of a heat source modulated by the term (1).

II. RESULTS

A. *Steady stade of the oscillator*

The steady simulation allows to forecast the temperature field of the OCXO and to determine the best layout regarding the main active components. Moreover, an utter thermal map of the device can be post -processed to carry out an accurate "part-stress analysis".

The simulations carried out at -30° Celsius show that the uniformity of the heat distribution around the quartz is good. (figure (3) and (5)) Regarding the position of the main actives components, an optimized layout has been reached in order to avoid important offsets and to heat uniformly the oscillator board (figure (4)).

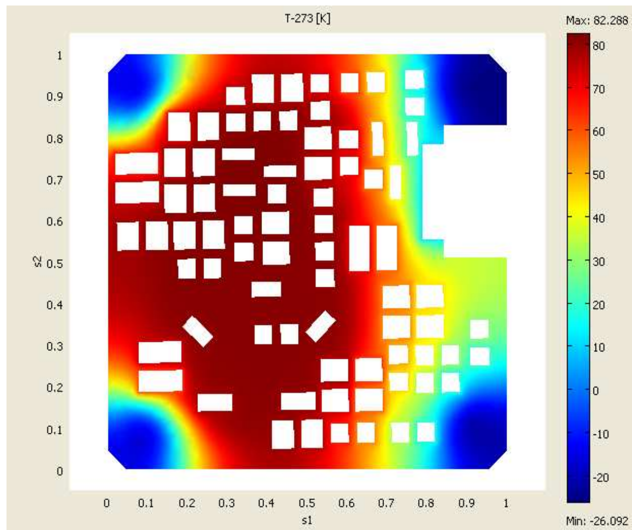

Figure 3 : Thermal map of the regulated board

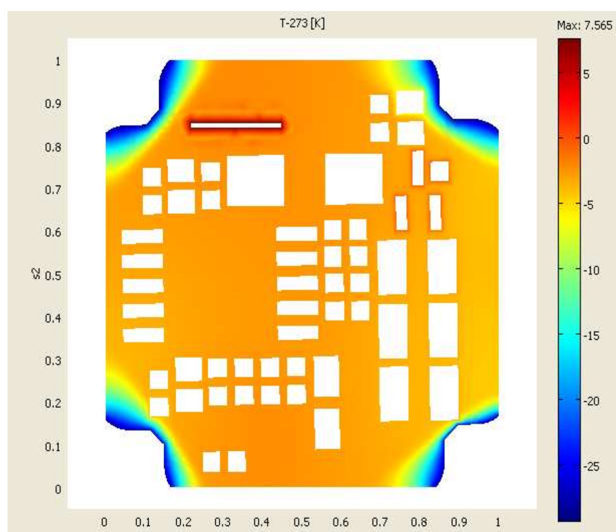

Figure 4 : Thermal map of the oscillator board

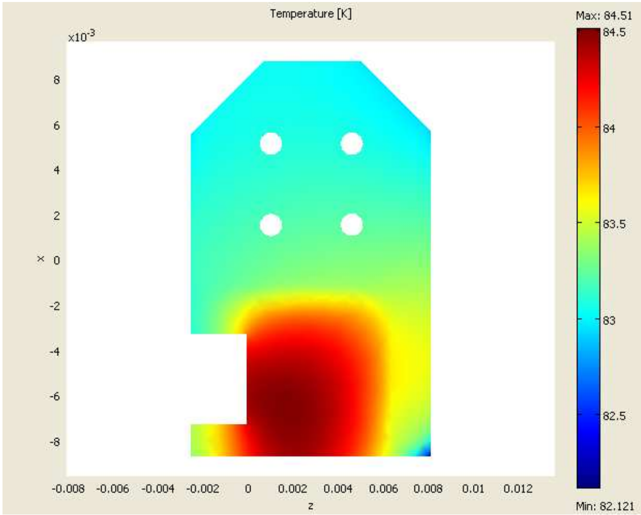

Figure 5 : Thermal map of the mass plan above the quartz

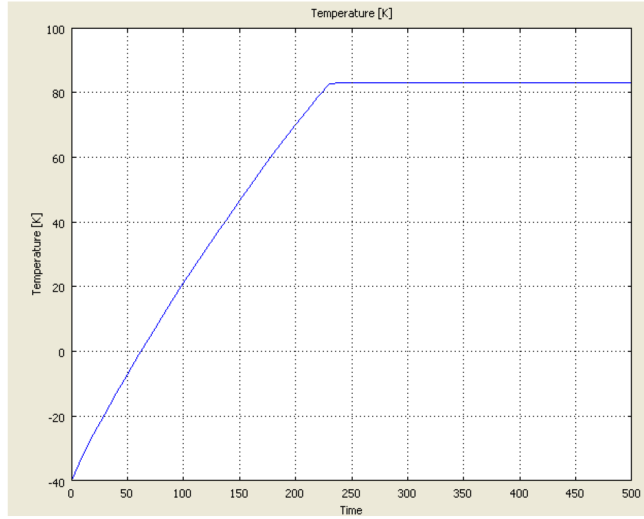

Figure 6 : sensor temperature evolution

B. Warm up simulation

The unsteady simulation allows us to forecast the behavior of the regulation by implementing the temporal term of the equation (1) into **COMSOL.** The set point of the regulation is 83° and the maximal power released by the heat transistor is one watt. All these values are the nominal one at the beginning of the device life. A worst case could be carried out with value corresponding to the drift of the set point and of the power due to any factor (aging, failure…..).

The parameters Kp and Ki are chosen with values near from similar designs. Since there are simple mathematic relations between the proportional and integral constant and the component values, it is even possible to optimize the regulation behavior. In a first time nevertheless, we only take care about a thermal transient without any consideration about the optimization.

The response of the system is studied. The exterior temperature is -30° and the relevant parameter studied is the sensor temperature. The warm up time is about 300s and the regulation parameters seem to be well tuned since no significant oscillations are observed (figure (6)). The figure (7) confirms this fact; the power released by the heat transistor is never totally shut down.

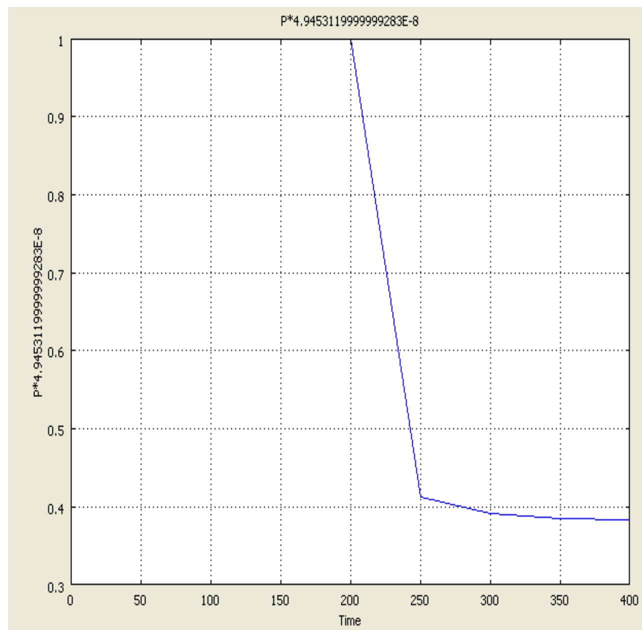

Figure 7: heat transistor power evolution

C. Quartz package simulation

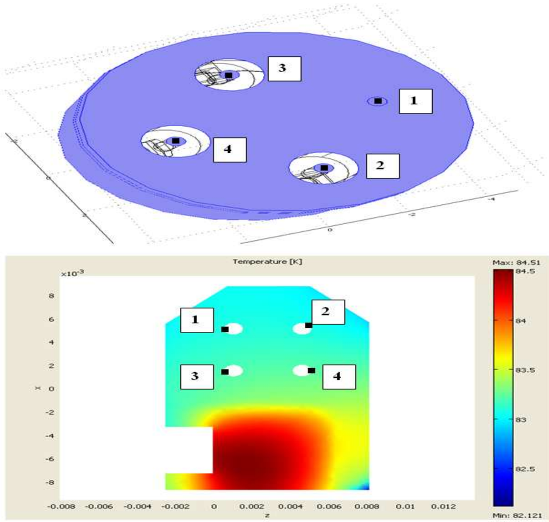

Figure 8 : entrance data for the quartz simulation

The data from the previous simulation will serve as boundary conditions for the quartz package simulation. Hence, the temperature calculated at different point corresponding to the quartz leads of the copper plan above the quartz constitutes a "temperature fixed "boundary condition (figure (8)).

The result shows a good homogeneity of the temperature field on the quartz. The maximal temperature gradient is about 0.1° which is quite a correct value.

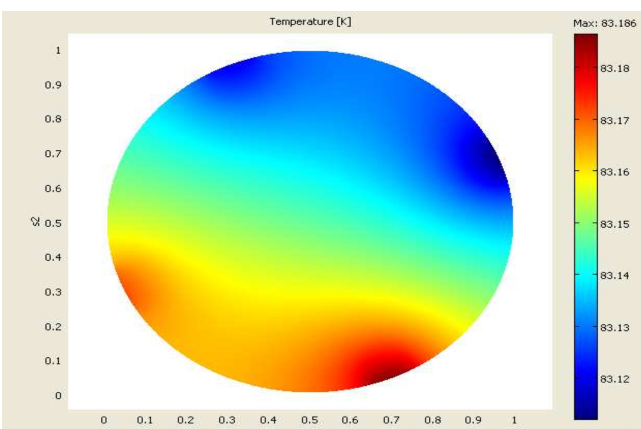

Figure 9 : quartz thermal map

D. experimental validations

Experimental validations have been carried out. The difference between simulation and experimental results is about 25 % on the consumption value (see figure 10). The difference lies in one main reason. Since the computation power is limited, we haven't represented the copper track between the pads and some details like fine internal copper tracks, non active components or vias. Therefore the consumption is logically underestimated. Since adding all the simplifications impacts the final incertitude, a systematic endeavour will be made in order to represent all the details of the oscillators. Nevertheless, this degree of accuracy is reasonable and a factor of safety will be systematically taken into account in the future simulation if the memory requirement of the model is exceeded by adding small details.

Regarding to the warm-up time and regulation behavior, the simulation result fit correctly with the experimental results with a difference of 15% (figure 11)

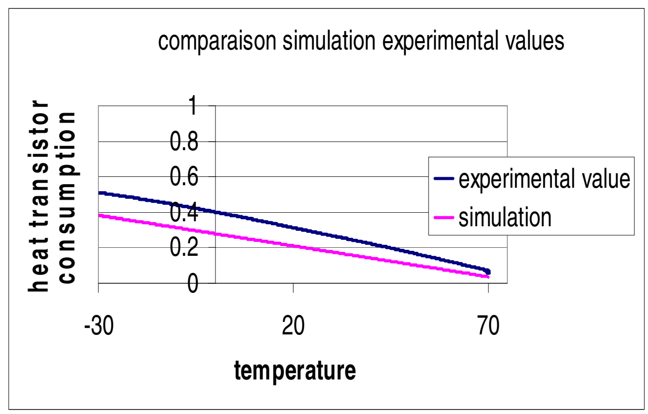

Figure 10 : comparaisons of experimental and simulation of the OCXO consumption

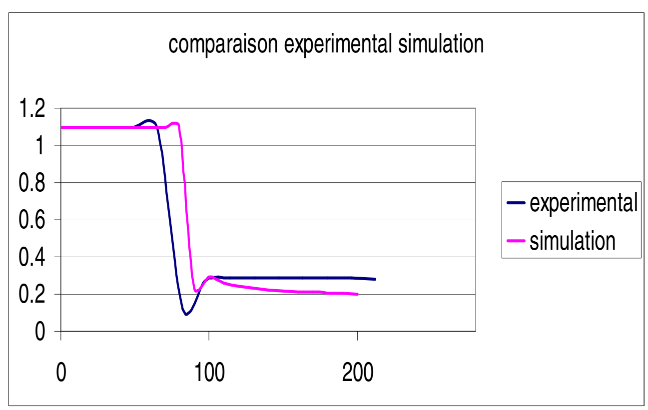

Figure 11 : comparaisons of experimental and simulation of the OCXO warm up at 25°celsuis

III. CONCLUSION

Numeric prototype of an OCXO has been simulated with the help of COMSOL allowing us to reduce development time. The same modelisation procedure will be carried out to develop other oscillators like USO (ultra STABLE OSCILLATOR). The maximal amount of details allowed by the memory resources of the computer as well a margin of safety will be systematically taken into account in the simulation; the consumption obtained by simulation will be multiplied by a factor 1.25 to estimate the real consumption conservatively.

REFERENCES

[1] www.flomerics.com/files/casestudies/1295/Board_Level_Thermal_Design_-12_28_07_(2).pdf

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