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A Study on Stochastic Thermal Characterization of Electronic Packages

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ABSTRACT
Insofar as the electronics can be found now in several applications of multiple domains, we have tried to highlight in this study that, those systems must be based on unquestionable reliability and meet the needs of the external environment. Starting from the unit "°c / w" concerning the thermal resistance from the gap between junction temperature and a reference temperature, we have tried to compare the thermal performance of electronic packages taking into consideration the thermal management. Our approach is based on the Monte Carlo simulation and the stochastic characterization of the QFN. From the norm of normalization, we have obtained standardized data sheets allowing accurate comparisons of the thermal performance of electronic packages as produced by different manufacturers. Our numerical model through simulation, prototyping concerning the design involves the JEDEC recommendations, which we consider a very interesting alternative. Through the deterministic analysis, we conducted an analysis from the Matlab program parameters, which control the Ansys software, the results were processed by statistical techniques to evaluate the times of the thermal resistance of the QFN. That is why we must consider the electronic package (encapsulating the integrated circuit), through the printed circuit board (PCB) to ensure the junction temperature maintenance and avoid the dissipation of the heat. Also our process was based on the union of the finite element method to the Monte Carlo simulation and stochastic characterization of the QFN.

Keywords: Electronic package; Finite element method; printed circuit board (PCB); Quad Flat No Lead (QFN); Simulation of Monte Carlo; Thermal resistance.

I. INTRODUCTION

Nowadays electronics play a crucial role in several applications: medicine, embedded systems of transportation, and telecommunication. While achieving electrical functions, electronic systems must be safe, reliable, have low thermal resistance (to dissipate the heat properly) and must be durable and insensitive to the exterior environment variations (humidity, thermal and mechanical shock ...). [1]

All integrated circuits generate heat when power is applied. Therefore, to maintain their junction temperature below the maximum allowed, electronic package dissipate the effective heat (encapsulating the integrated circuit) through the printed circuit board (PCB) and to the ambient air is essential [2]-[3].

Thus, we should take in account the thermal management when selecting electronic packages to ensure high reliability of the final product. Indeed, designers of electronic systems must have at their disposal the thermal performance of electronic packages to determine their environmental limits. Thermal resistance is a data, which allows the engineers to compare the performance of electronic packages of different suppliers. This data is being assessed in an experiment aligning with international standards.

A key assumption during the thermal characterization of electronic packages is that the problem is deterministic, meaning that the parameters of the problem are constant. However, by making a few experiments, we concluded the limits of a deterministic modeling. Indeed, there are always differences between calculated quantities and those measured. The causes are related to the uncertainties in the geometry, material properties, boundary conditions or loads. This has a considerable influence on the thermal behavior of electronic systems. Hence, the interests to take account these uncertainties and determine the dispersions of the output (thermal resistance) [4].

II. THERMAL RESISTANCE

The characterization of the thermal performance of an electronic package was created through the "heat resistance". This parameter, which is appealed by « θ » is internationally evaluated, compared, and operated by industrial electronics. This latter is the measure of the ability of a package to transfer heat generated by the integrated circuit (die) to the ambient air or to the PCB. Practically, the thermal resistance is the difference between the junction temperature and the steady state reference temperature for each watt of heat flux generated by the upper surface of the die. Its unit is « c° / w ».

The thermal resistance of the junction at room temperature « θ_{JA} » is the commonly used to compare the thermal performance of the electronic package. It is evaluated via the equation (1) knowing that «TJ » and « TA » are respectively the junction temperature and the ambient temperature (Fig.1).

$$\theta_{JA} = \frac{T_J - T_A}{\text{Power of Die}} \left[c°.w^{-1} \right] \qquad (1)$$

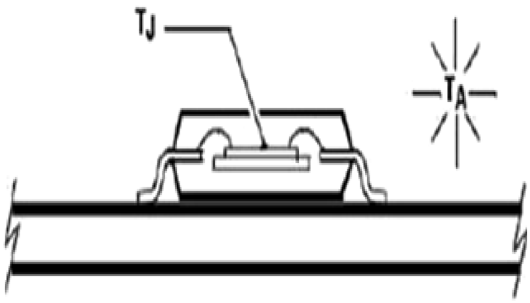

Fig.1.T_J and T_A

III. NORMS

The evaluation of the thermal resistance of an electronic package is as follows: the latter is welded onto a PCB. We fuels the die, once the steady state is established; the junction and ambient temperatures are reported via thermocouples, and finally, the resistance is calculated using the equation (1). The factors, which can influence the evaluation of «θ_{JA}» (except for the concerned package), are:

- Geometry (dimensions and thickness) and the PCB's materials.
- The countenance rates of the PCB in copper.
- The orientation of the PCB (horizontal or vertical).
- The volume of the air surrounding the PCB and flow velocity.

In order to eliminate the influence of these factors on the thermal performance they must report the industrial packaging on the data sheets of their products; standards were developed and adopted by "Electronics Industries Association (EIA)". These standards describe the procedures and settings with which we must align during thermal characterization of electronic packages. The purpose of this standard is to have standardized data sheets to enable an accurate and meaningful comparison of the thermal performance of electronic packages produced by different manufacturers.

3-1 Three standardized tests for basic PCB

The JEDEC standards [3] focus mainly on the PCB used for measures seen the major influence of the latter. Thus, three standardized PCBs are used for the assessment of « θ_{JA} »:

- "Low Effective" Thermal Conductivity Board (1S0P: Top surface of Cu traces only);
- "High Effective" Thermal Conductivity Board (1S2P: Top surface of Cu traces buried planar Cu + 2);
- "High Effective" Thermal Conductivity Board with Features Direct Attach (1S2P+ Vias: Top Surface traces Cu + Cu + 2 buried planar+ thermal Vias).

The PCB Standards are in FR4 and have geometrical characteristics (Tab.I):

Table 1: Dimensions of PCB

PCB	114.3×76.2×1.6 (mm^3)
Buried Planes	74.2×74.2×0.035 (mm^3)

3-2 Units Standardized environmental conditions: air at rest case

According to the JEDEC standards [2], the PCB must be positioned horizontally (top package) in a closed chamber, which prevents the intrusion of air currents, allowing only the transfer of heat by natural convection with air at rest. The enclosure must have internal dimensions as nominal « 305 x 305 x 305 (mm3) » and must be made of low thermal conductivity material (less than 0.5 W / m.K). The enclosure is placed on a support also low thermal conductivity material.

IV. NUMERICAL MODEL

During the phase of design and prototyping, the standardized thermal characterization of electronic packages may prove costly in terms of time and means. Developing a reliable numerical model that is realistic and which integrates the JEDEC recommendations is a very interesting alternative. Thus, the designing of experiments can be carried out without limitations via the simulation.

In our case, the most appropriate approach is the one based on the finite element method combined with the method of Monte Carlo.

The finite element method allows the resolution of the heat equation, something you cannot achieve analytically due to the complexity of the geometry (PCB Electronics Package +). In this case, the output of the model is the temperature field, while the entries of the model of the finite elements are:

- Geometry: electronic package welded to a standardized PCB;
- Material properties: thermal conductivities of the various layers of materials;

- Load: the created power (By the Joule effect) on the upper side of the IC (die);
- Boundary conditions: natural convection with air at rest modeled via convection coefficients.

On the other hand, the estimation of the moments (average and variance) of the thermal resistance can be obtained by Monte Carlo simulation, [5] which we will combine with the finite element model. Despite its high cost in calculation time, this classic method is widely used and serves as a reference for approximate calculations. The thermal resistance « θJA » will be viewed as a random variable image of basic random variables. The simulations include the construction of a sample « $(\theta_{JA})1$, $(\theta_{JA})2$… $(\theta_{JA})n$ » of the random variable « θ_{JA} » and to treat this sample by the usual statistical techniques. The "n" simulations are carried out in an independent manner under the law of distribution of basic random variables.

V. STOCHASTIC THERMAL CHARACTERIZATION OF A QFN

In this work, we applied the proposed approach to characterize a type of electronic package "Quad Flat No Lead (QFN)" [6] (Fig.2) that is part of the family of packages with a scale similar to that of CI and which are welded directly on the PCB. The QFN has connections at its lower perimeter; they allow the electrical connection between the IC and the electrical PCB layout. It also has a thermal pad to increase the heat transfer.

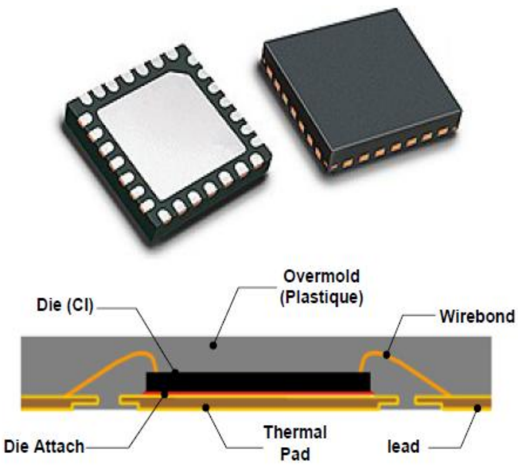

Fig.2.Quad Flat No leads (QFN)

The proposed package to be characterized is a « QFN -28 IO - 7.2 x 7.2 x 1.4 mm3 » and the dimensions and the material properties are shown in the figures below (Fig.3) and (Tab.II). The temperature of the ambient air is assumed «20°c ». While, the power generated by the IC is assumed to be «1 Watt».

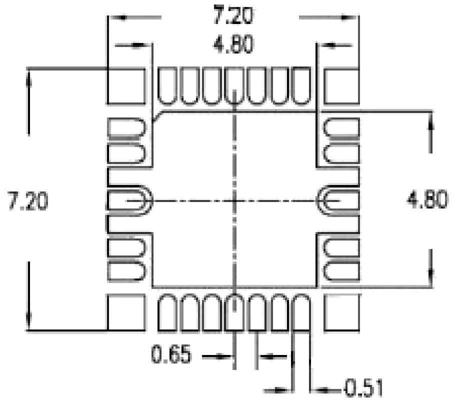

Fig.3. Dimensions of QFN

Table 2: Conductivities of the materials of QFN.

Component	**material**	**K[w/m.c°]**
Die	Si	148
Die Attach	Epoxy	60
Overmold	Epoxy	1.04
Cu	Cu	385
PCB	FR4	0.4
Solder	SnAg	55

Finite element analysis was performed using the commercial code "Ansys". We opted for a regular mesh (made possible by a programming script) whose elements are rectangular parallelepipeds at 8 knots (Fig.4). This allows for the control of the number of mesh layers and an increase in accuracy.

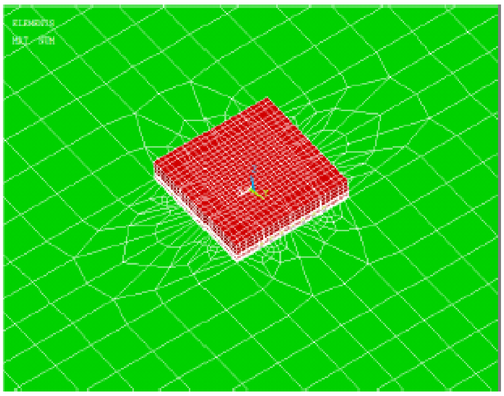

Fig.4. Mesh geometry of QFN welded on a PCB

5-1 Deterministic Analysis

At first, the thermal characterizations of the QFN were performed assuming that all the parameters of the problem are deterministic. The junction temperature output of the FE model is « 67°c » (Fig.5). Therefore, the thermal resistance of QFN is « 47 c°/w ». This result correlates with the thermal performance provided by electronic packages for QFN producers whose dimensions are close to those of QFN characterized in this work.

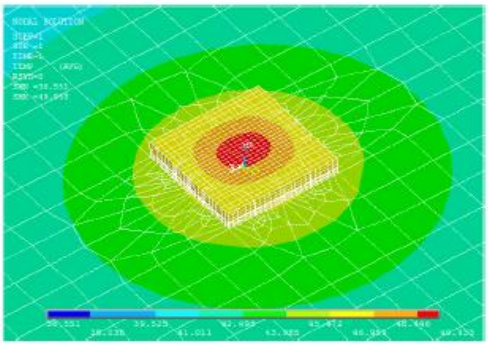

Fig.5. Temperature field result of FE model

5-2 Stochastic Analysis

The stochastic analysis was performed assuming that the following parameters are Gaussian when a standard deviation is « 8% » of the nominal value: Conductivity of PCB, PCB dimensions, IC's power and Ambient Temperature. 300 samples of the parameters have been created via a Matlab program that controls the Ansys software and gives the results to it. These are processed by statistical techniques to assess the times of the thermal resistance of the QFN. The results of the Monte Carlo simulation (Tab.III) show that the thermal resistance is sensitive to the input variations. Indeed, in our case, the standard deviation is « 12% ».

Table 3: Moments of the Thermal Resistance of QFN

	Average	Standard Deviation
θ_{JA} [c°/w]	47.35	5.75

VI. CONCLUSION

In this work, we have adopted an approach allowing the thermal characterization of electronic packages through simulation taking into consideration the uncertainties. This approach consists of combining the finite element method with the Monte Carlo simulation. Stochastic characterization QFN revealed a significant dispersion of its thermal resistance. This information is crucial; it will allow for the development of more reliable electronic systems, since the consideration of the dispersions of the resistances in the design will define realistic junction temperatures that do not exceed their limits.

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