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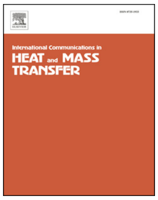

Experimental and Numerical Study of Natural Convection for High Powered and Wire-Bonded QFN64b Electronic Device☆

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ABSTRACT

The main objective of this work is to quantify the free convective heat transfer concerning the wire-bonded version of the QFN electronic device equipped with 64 leads. This package denoted as QFN64b generates a high power varying between 0.1 W and 1.0 W by steps of 0.1 W. It is welded on a Printed Circuit Board (PCB) which may be inclined with respect to the horizontal plane by an angle ranging from 0° (horizontal position) to 90° (vertical position) by steps of 15°. These power and inclination angle ranges correspond to the normal operation of the device for the intended application. The electronic assembly is installed into a small air-filled parallelepipedic box. Correlations are proposed to calculate the average convective heat transfer convection according to the generated power and the inclination angle on five specific assembly areas. The work done by means of a numerical approach using the finite volume method is complemented by an experimental study. The calculations are in good agreement with measurements, confirming the validity of the proposed correlations. These tools allow a better thermal control of these devices increasingly used in electronics. They complement the recent results related to the same assembly considering lower generated power ranging between 0.01 and 0.1 W, corresponding to the partial operation of the electronic equipments.

1. Introduction

The technique of wire bonding is widely used in modern arrangements including the Quad flat non-lead (QFN) electronic devices. Technical specifications can be consulted in many documents including [1,2]. Their heat source is connected to the leads by means of wires constituted by the combination of high thermal conductivity materials as Gold, Aluminium, Copper, Silver and Nickel. This technique described in several documents as [3,4] is mainly used to lower the junction's average temperature. Higher powers can then be considered without exceeding the maximum temperature recommended by the manufacturers, thus avoiding malfunction, shutdown or destruction. The reliability of the wire-bonded QFN is improved compared to that of the basic version. The wires connections modify the heat transfer phenomena in the electronic assembly during its operation. Heat is drained by pure conduction to the leads and then to the PCB on which the component is welded. Given its well-known advantages, natural convection is favored in electronics. It eliminates various drawbacks of thermoregulation techniques by forced convection that use mechanisms such as fans. These are sources of acoustic and electromagnetic pollution, and need to be powered and regulated. They present also risk of failure, thus decreasing the reliability of the assemblies. Given its interest in applications, natural convection is widely covered in the literature. Several parameters affecting the dynamic and thermal characteristics of the flow are discussed. The size and geometry of the boxes containing the electronic assemblies have been addressed in several works including [5–13]. The quality of the convective fluid is also presented in works as [14–16] addressing nanofluids, known for the enhancement of the natural convective heat transfer. Other techniques applied to the field of electronics are available in [17–21]. Convective heat transfer concerning the basic QFN16 and QFN32 packages have been quantified in the recent surveys [22–23]. Several configurations combining the power generated by these devices and their inclination relative to the gravitational field were treated. Correlations are proposed to calculate the average convective heat transfer convection according to the generated power and the inclination angle. They allow a better control of these devices during their operation and optimize their thermal design. The model equipped with 64 independent wire-bondings, denoted as QFN64 is used in specific assemblies, given its particular characteristics which distinguish it from the two models QFN16 and QFN32. Its thermal behaviour in the assemblies being different for the same generated power, it is necessary to characterize it thermally when it is subjected to surface phenomena. Natural convective heat exchange concerning the basic QFN64 model was quantified in [24] by means of correlations allowing calculation of the average convective heat transfer convection for

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Nomenclature

A_i	area of the i^{th} element of the considered area (m^2)
g	gravity acceleration ($m\ s^{-2}$)
h_i	local convective heat transfer coefficient ($Wm^{-2}\ K^{-1}$)
$\overline{h}$	average convective heat transfer coefficient for a given area ($Wm^{-2}\ K^{-1}$)
I	current intensity (A)
m	number of elements of the considered area (−)
P	generated power (W)
P'	natural convective power exchanged by a giving area (W)
P^*	ratio defined by $P^* = P'/P$ (−)
P_R	radiative power (W)
P_R^*	ratio defined by $P_R^* = P_R/P$ **(−)**
R	resistance (Ω)
T	temperature (K)
$\overline{T}$	average temperature (K)
T_c	cold temperature and initial temperature of the whole system (K)
$\overline{T_m}$	average measured temperature (K)
T_i	local temperature of the i^{th} element (K)

Greek symbols

αZ	inclination angle with respect to the horizontal (°)
δI	absolute uncertaintiy of I (A)
δP	absolute uncertaintiy of P (A)
δR	absolute uncertaintiy of R(Ω)
$\Delta\overline{T}$	temperature difference, $\Delta\overline{T} = (\overline{T} - T_c)$(K)
$\Delta\overline{T_m}$	measured temperature difference (K)
λ	air thermal conductivity ($Wm^{-1}\ K^{-1}$)

specific conditions: low generated power ranging between 0.01 W and 0.1 W (partial operation of the electronic equipments) and inclination angle varying between 0 and 90° corresponding to the horizontal and vertical positions respectively. A similar work [25] concerning the wire-bonded version of the QFN64, denoted as QFN64b, has been recently published. However, to the knowledge of the author, the natural convective heat transfer has never been quantified for this device generating power greater than 0.1 W.

This is the objective of the present work regarding high powered QFN64b that generates power varying between 0.1 W and 1.0 W by steps of 0.1 W. The package is welded on a Printed Circuit Board (PCB) which can be tilted with respect to the horizontal by an angle ranging from 0° to 90° by steps of 15°. These power and inclination angle ranges correspond to the normal operation of the device for the intended application. The correlations proposed in this work allow determination of the free convective heat transfer coefficient for all the treated configurations in various specific areas of the assembly. The survey done by means of a 3D numerical approach using the finite volume method is complemented by an experimental approach performed on a prototype in order to measure the generated power and the temperature field. The calculations are in good agreement with measurements, confirming the validity of the proposed correlations.

2. The considered configurations

The wire bonded QFN64b device presented in Fig. 1(a) can be modeled as a parallelepiped (square of 9 mm side, 1 mm height). Its technical characteristics are available in various documents as [1–2]. In short, its active source is the top layer (1) of the parallelepipedic die (2) fixed on the diepad (3) by means of a thin paste layer (4). The source is connected to the 64 leads (5) with a high thermal conductivity wires (6) of 25 μm diameter. The wires are regularly distributed on the top surface in order to homogenize its temperature during operation. The high power P generated by the source during operation ranges from 0.1 W to 1.0 W. The corresponding volumetric heat flux is assumed to be constant. The whole device is encapsulated by means of a molding compound (7). The QFN64b package is welded on the center of a Printed Circuit Board (PCB, square of 40 mm side, 1.6 mm thick) presented in Fig. 1(b), which could be inclined with respect to the horizontal plane by an angle α varying between 0° (horizontal position) and 90° (vertical position) by steps of 15° (Fig. 1(c)). The assembly is installed in an air-filled parallelepipedic box (length 48 mm, width 32 mm, 8 mm thick), whose walls are maintained isothermal at $T_c = 293.15K$. The temperature distribution in the assembly is highly dependent on the thermal conductivities of the device's materials. The values considered here are 147, 308, 300, 3.1, 0.66 and 300 $Wm^{-1}\ K^{-1}$ for the die, the diepad, the leads, the paste, the molding compound and the wires (associations of Au, Ag, Cu) respectively. They are considered as constant and temperature-independent and the materials are assumed as isotropic for the conductive point of view. The PCB's equivalent thermal conductivity are set to 20 $Wm^{-1}\ K^{-1}$ in the board's plane and 0.35 $Wm^{-1}\ K^{-1}$ in its thickness. The considered assembly is decomposed into 6 distinct areas represented in Fig. 1(b). The top face, the sides and the back face of the QFN64b are denoted as (Q_T), (Q_S) and (Q_B) respectively. The (Q_B) back face is introduced in the numerical approach of this work to facilitate the device modeling. The top face (except the (Q_B)'s mark), the sides and the back face of the PCB are denoted as (B_T), (B_S) and

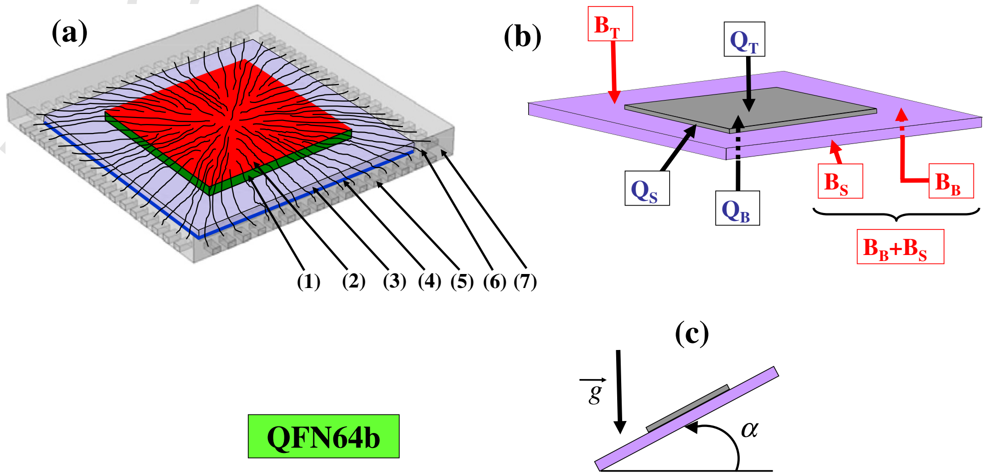

Fig. 1. (a) the wire bonded QFN64b package (b) the device welded on the PCB and the areas of the assembly (c) the inclination angle α with respect to the horizontal plane.

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