

EFFECTS OF THE RESIN'S THERMAL CONDUCTIVITY ON TEMPERATURE OF THE QFN64 ELECTRONIC DEVICE SUBJECTED TO FREE CONVECTION

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ABSTRACT

The reliability, durability, performance and correct operating of the quad flat non lead 64 (QFN64) packages are directly linked to their thermal state. In some works published recently, the thermal conductivities of the materials constituting the package are assumed as isotropic and temperature independent, corresponding to the average values considered in similar studies. These important characteristics can however vary depending on the manufacturing process of the device and the used materials. The molding compound's thermal conductivity (resin) used for encapsulating the QFN64 package significantly affects the thermal behaviour of this electronic package during operation when it is subjected to natural convection. These effects are quantified in this work by varying this conductivity between -80% and + 80% of its average value. The 3D numerical solution done by means of the control volume method clearly shows that the maximal temperature reached into the source of this device is affected by this parameter for a wide range of the generated power and various inclinations of the device relative to the horizontal. The correlation proposed in this work allow optimizing the thermal design and increase the reliability of this electronic device widely used in various engineering fields.

NOMENCLATURE

g	[m.s ⁻²]	gravity acceleration
P	[W]	generated power
T_c	[K]	environment temperature and initial temperature of the whole system
T_{max}	[K]	maximal temperature
T^*	[-]	dimensionless temperature

Greek symbols

α	[°]	PCB's inclination angle relative to the horizontal
λ_m	[Wm ⁻¹ K ⁻¹]	molding compound's thermal conductivity
$\overline{\lambda_m}$	[Wm ⁻¹ K ⁻¹]	average λ_m value
λ^*	[-]	dimensionless λ_m value; $\lambda^* = \lambda_m / \overline{\lambda_m}$

ΔT_{max} [K] temperature difference; $\Delta T_{max} = T_{max} - T_c$

INTRODUCTION

Several works are devoted to improve the performance of Quad Flat No-lead (QFN), given their various advantages. Their very small weight (a few mg) and reduced volume varying from about (0.8x1.5x2.0)mm³ to (1.0x9.0x9.0)mm³ allows installing them in many common equipment like mobile phones. Various industrial sectors are concerned by these devices whose details, characteristics, thermal test methods and more information can be found in various documents and technical notes as [1-4]. A large part of the research for the development of these devices is devoted to thermal aspects. The natural convective phenomena concerning the QNF16 and QFN32 models as well as their wire-bonded versions denoted as QNF16b and QFN32b have been qualified in recent works [5-10]. Correlations quantifying the natural convective heat transfer coefficient concerning different areas of the assembly are proposed. Other correlations highlighting effects of the PCB's Copper ratio on the free convective heat transfer for a tilted QFN32 electronic package are proposed in [11]. To increase the power generated by the source of the device while maintaining the same volume and even reducing it, it is necessary to find the heat dissipation means for the generated power density reaching several GWm⁻³. Exceeding the critical temperature junctions recommended by the manufacturers greatly reduces the assembly's reliability, causes premature fatigue of the components and leads either to failure or to the destruction of all or part of the assembly. This problem is exacerbated by the fact that cooling is often performed by natural convection to avoid external mechanisms associated to the forced convection techniques. The well known electromagnetic and acoustic disturbances associated to the fan operation and their disadvantages (excess weight, volume, necessity of power, ...) are prohibited in many arrangements, particularly in onboard electronics field. Heat sink modules devices are often used in cooling electronics systems. The numerical study by Huang et al. [12] based on the Levenberg-Marquardt Method (LMM) is devoted to the optimization of the

heat sink shape. The calculations are completed by some temperature measurements by means of a thermal camera. When high power levels are generated as it is the case for the QFN64 model, natural convective heat exchange is sometimes insufficient when air is the convective fluid, as it is preferred by engineers in many electronic applications. Other fluids are then used such as the nanofluids. An interesting comparison between natural convective exchange with and without nanofluids is proposed in the review by Öztop et al. [13]. Otherwise, some thermal problems may occur during the manufacturing process of the QFN package, due to the thermosetting polymers used for its encapsulation. The numerical survey of Yang et al. [14] considering a cure-dependent viscoelastic constitutive model allows examination of the material's characteristics all along the curing process of the thermosetting polymer. Some experimental results confirm that the material coefficient of thermal expansion (CTE) greatly influences the warpage phenomenon and thus the performance of the QFN package. The correct choice of the encapsulation material is very important for the package manufacturing process. The Quad Flat No-lead in general, and especially the QFN64 model examined in the present study are composed by various elements presented and summarized in the following section. Their materials are very different and have thermal properties (conductivity, coefficient of thermal expansion, specific heat, thermal diffusivity ...) very different. The thermal behaviour of the device during operation is highly dependent on the values of these characteristics.

The molding compound's thermal conductivity (resin) used for encapsulating the QFN64 package significantly affects the thermal behaviour of this electronic package during operation when it is subjected to natural convection. These effects are quantified in this work for molding compound's thermal conductivity ranging between -80% and + 80% of the average value generally used in the works. The 3D numerical solution done by means of the control volume method confirm that the maximal temperature reached into the source of this device is very affected by this parameter for a wide range of the generated power and various inclination angle of the device relative to the horizontal. The correlation proposed in this work allows optimizing the thermal design and increases the reliability of this electronic device widely used in various engineering fields.

TREATED CONFIGURATION. NUMERICAL SOLUTION

The considered QFN64 package is schematically presented in Fig. 1(a) and its dimensions are detailed in Fig 1(b). The Die (1) constitutes the hot element of the device. Its surface layer (2) is active, generating a constant power denoted as P . The Die is fixed to the Die pad (3) located at the bottom by means of a thin paste layer (4). The 64 leads (5) connect the package to the electronic assembly, and the whole device is encapsulated by means of a molding compound (6) whose effects on the device's temperature distribution are especially examined in this work. The QFN64 package is therefore modelled as a $(9 \times 9 \times 1) \text{ mm}^3$ parallelepiped, welded on a large printed circuit board (PCB), installed in a air-filled enclosure

whose dimensions are sufficiently large compared with those of the PCB to not disturb the flow around the PCB and the QFN.

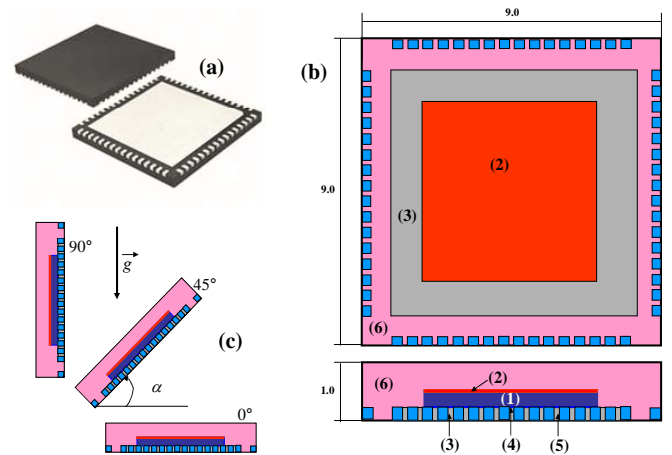


Fig. 1. (a) The treated QFN64 package; (b) Details and dimensions (in mm) of the device; (c) The 3 treated inclination angles α .

The PCB may be inclined with respect to the horizontal plane by an angle α equal to 0° (horizontal position), 45° and 90° (vertical position) as represented in Fig. 1(c). These positions correspond to the actual situations of the industrial electronic assembly considered here. In this steady state survey, the device's materials are assumed to be thermally homogeneous. Their thermal conductivities considered as isotropic are set to 147, 308, 300 and $3.1 \text{ W m}^{-1} \text{ K}^{-1}$ for the Die, the Diepad, the leads and the paste respectively. That of PCB is equal to 20 and 0.25, in its plane and its thickness respectively.

The present survey is focused on the effects of the molding compound's thermal conductivity λ_m on the maximal temperature reached in the source. Five particular values of λ_m will be considered, around the average value $\overline{\lambda_m} = 0.7 \text{ W m}^{-1} \text{ K}^{-1}$ typically used in some works such as [5-11] examining the QFN 16 and 32 models. The dimensionless molding compound's thermal conductivity defined as

$$\lambda^* = \lambda_m / \overline{\lambda_m} \quad (1)$$

has in this work five discrete values: 0.2, 0.6, 1.0, 1.4 and 1.8.

In the numerical procedure, the whole domain including the air are initially isothermal at temperature $T_c = 20^\circ \text{C}$, under standard atmospheric pressure. The active part of the Die generates a power P varying between 0.2 and 1.0W by steps of 0.2W. The no-slip condition is assumed on all the internal walls of the enclosure and the assembly. The air is assumed to be incompressible, the Boussinesq approximation is applied and values of the other air thermophysical properties are evaluated at the average temperature of each control volume. Given that the present study is focused on the convective phenomena, radiation is not considered. This condition is

realized by imposing a global infrared emissivity equal to zero at all the walls of the system. Calculations are done by means of the commercial software Ansys-Fluent [15] based on the control volume method and using the SIMPLE algorithm. The main parameters as the temperature gradient at the surface of every element are exported into a specific software developed in the research group (LTIE) in order to calculate the local convective heat transfer around the QFN package and the maximal temperature reached in its source. The mesh consists of parallelepipedic elements as detailed in Fig. 2., refined all around the package. The convergence criteria in the numerical process are set to 10^{-5} for the velocity components and 10^{-6} for energy. Such condition is attained in this work with 840,154 elements.

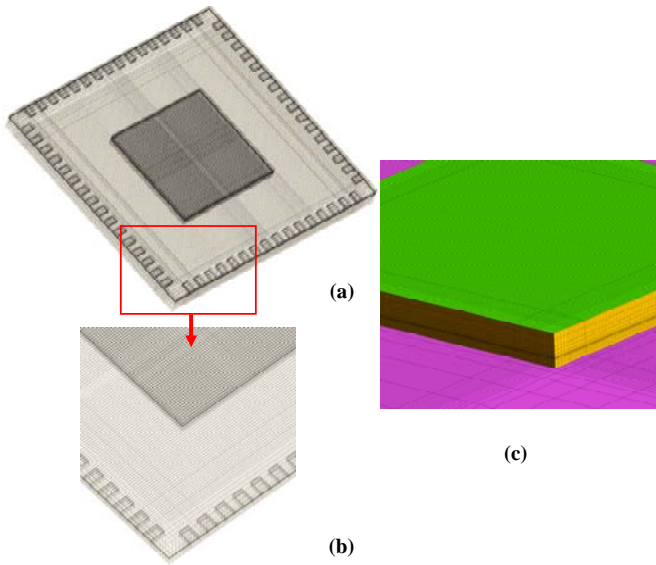


Fig. 2. (a) the adopted mesh for the QFN64 package; (b) detail of (a); (c) detail at interface QFN64-PCB

RESULTS

Calculations are performed by combining:

- * 3 inclination angles $\alpha = 0, 45$ and 90° ;
- * 5 generated power $P = 0.2 - 1.0$ step $0.2W$;
- * 5 dimensionless molding compound's thermal conductivity $\lambda^* = 0.2, 0.6, 1.0, 1.4, 1.8$

Evolution of the temperature difference $\Delta T_{max} = T_{max} - T_c$ versus λ^* is presented in Fig. 3 for $\alpha = 0$ and $P = 1W$, being T_{max} the maximal temperature of the system (within the active source). The calculated discrete values are the black circles whose evolution is modelled by a function of the exponential type (red line with red squares discrete values).

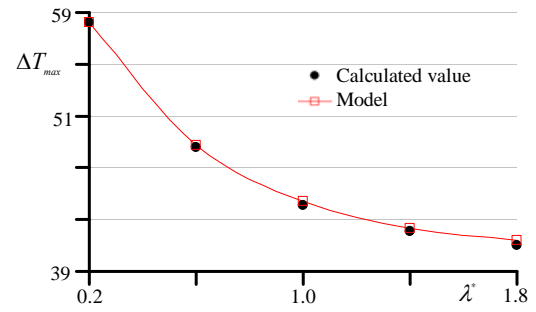


Fig. 3. Evolution of $\Delta T_{max} = T_{max} - T_c$ versus λ^* for $\alpha = 0$ and $P = 1W$

This figure illustrates perfectly the effect of the molding compound's thermal conductivity λ_m on the maximal temperature reached in the electronic device. This temperature decreases of $17.2^\circ C$ when the conductivity varies between -80% and $+80\%$ of the average value $\bar{\lambda}_m = 0.7 \text{ Wm}^{-1}\text{K}^{-1}$. The same work done for the other considered (α, P) values lead to similar ΔT_{max} trends, as represented in Fig. 4 for the combinations of $(\alpha = 0, 45^\circ, 90^\circ)$ with $(P = 0.2, 0.6, 1W)$.

Finally, the value of $\Delta T_{max} = T_{max} - T_c$ can be calculated according to the (α, P, λ^*) combination by means of the following correlation:

$$\Delta T_{max}(\alpha, P, \lambda^*) = A \exp\left(-\frac{\lambda^* - 0.2}{0.52}\right) + B \quad (2)$$

Valid for

$$\begin{cases} \text{QFN64} \\ \alpha = 0, 45, 90^\circ \\ 0.2 \leq P \leq 1.0W \\ \lambda^* = 0.2, 0.6, 1.0, 1.4, 1.8 \end{cases}$$

The coefficients A and B are presented in Table 1. Their evolution presented in Fig. 5 is clearly linear.

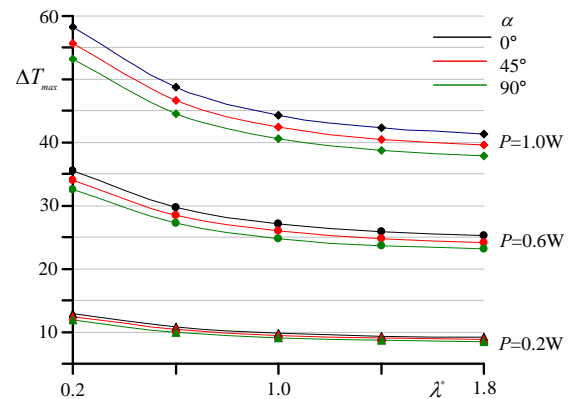
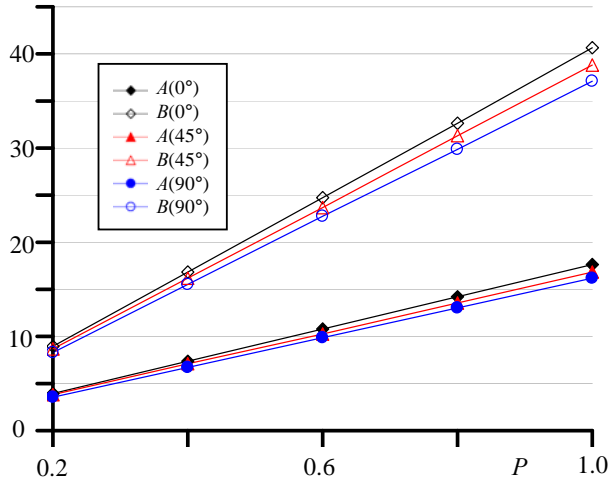


Fig. 4. Evolution of ΔT_{max} versus λ^* for the combinations of $(\alpha = 0, 45^\circ, 90^\circ)$ and $(P = 0.2, 0.6, 1W)$

Table 1: Values of the coefficients A and B in the correlation

$$\Delta T_{max}(\alpha, P, \lambda^*) = A \exp\left(-\frac{\lambda^* - 0.2}{0.52}\right) + B$$

α	P (W)	0.2	0.4	0.6	0.8	1.0
0°	A	3.90	7.34	10.77	14.20	17.60
	B	9.00	16.89	24.78	32.68	40.6
45°	A	3.76	7.04	10.32	13.60	16.88
	B	8.65	16.20	23.74	31.29	38.83
90°	A	3.60	6.74	9.87	13.00	16.13
	B	8.30	15.50	22.70	29.90	37.09

**Fig. 5.** Evolution of the coefficients A and B for the correlation

$$\Delta T_{max}(\alpha, P, \lambda^*) = A \exp\left(-\frac{\lambda^* - 0.2}{0.52}\right) + B$$

CONCLUSION

This survey clearly highlights the effect of the molding compound's thermal conductivity on the maximal temperature reached in the QFN64 electronic device subjected to natural convection. The maximum temperature localized in its active source increases by approximately 32% when the average value of the conductivity is decreased by 80%. It decreases by about 7% when the conductivity is increased by 80%. This observation remains valid throughout the power range generated by the source and all inclinations of the device relative to the horizontal plane. The correlation proposed in this work allows the calculation of the maximum temperature in the device according to its tilt angle (0, 45 and 90°) and the generated power (ranging between 0.2 and 1.0W by 0.2W step). A wide range of the molding compound's thermal conductivity is considered, varying between -80% and +80% of the average value generally considered in similar studies. Simple and easy to use, this correlation allows optimizing the thermal design of this electronic device widely used in various engineering fields, and increases its reliability.

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