Evaluation of Effective Thermal Conductivity in PCB

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Abstract

PCB is made of composite materials. PCB consists of a sheet of insulating material, small holes are provided on this sheet for accommodating different components of the circuit to be assembled. A piece of base material on which components are mounted, an insulating material along with the bonding material covered with copper foil gives copper cladded laminates. A laminates is essentially a stack of lamina oriented in different directions, the term layup refers to the composition of laminate. Thermal analyzer are usually posed with the job of predicting the temperatures along and across the plane of PCB(thickness) to understand better effect of thermal gradients and stagnation of heat. The main requirement here is to determine the effective orthotropic physical properties of a copper cladded laminate (PCBs). The use of the "effective" implies properties of the entire laminate i.e. to evaluate effective thermal conductivity, density and specific heat of PCBs, but the in this paper its discussed only to evaluate the effective thermal conductivity.

Keywords: Effective k in laminates, Electronic PCB, Bcond, Lux-pcb

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I. Introduction

Electronic equipments have made inroads into almost every aspects of modern life, from toys and appliances to high power computers. The continued miniaturization of electronic systems has caused drastic increase in the amount of heat generated per unit volume. A printed circuit board is properly wired plane board made of polymers and glass-epoxy materials on which various components such as the ICs,diodes, transistors, resistors and capacitors are mounted to perform the desired task. The PCBs are commonly called cards, and they can be replaced easily during repair. The PCB s are plane boards, usually 10 cm wide, 15 cm long and only a few millimeters thick. Usually a copper cladding is added on one or both sides of the board. The power dissipated by a PCB varies from 5W to about 30W. a typical electronic package involves several layers of PCB s which are cooled by air flowing between the boards. PCBs can be single sided, double sided and multilayered, depending on the use of low medium and high density devices. Glass-epoxy laminates made of an epoxy or polyamide matrix reinforced by several layers of woven glass cloth are commonly used in making circuit boards.

The thermal design of a PCB, it is important to pay particular attention to the components which cannot withstand high temperatures, such as capacitors, and to ensure their operation. Even when one component fails, the whole board fails to function and needs to be replaced.

Its weight/unit area, the most commonly used thickness being one ounce (0.035mm) and two ounces(0.07mm), always refers to the thickness of the copper cladding on the laminated board material. The standard pcb thickness is 1. 57mm.Analytical equations are essential to predict thermal conductivities of a composite material. Information on the thermal properties of composite materials would facilitate the design of an engineering system made of FRPs.

Published literature is rich with investigations of mechanical properties of composites (Gowayed, 1995). Fewer publications focused on thermal properties. Several publications like Hashin (1979), Caruso et al (1986), Muralidhar (1989), Springer and Tsai (1967) addressing different theoretical approaches for predicting thermal conductivity of composite materials have been noted. However, one of the publications (Gowayed, 1995) has discussed both transverse and axial thermal conductivity of a carbon fiber composite.

In this paper an algorithm is implemented to calculate the effective properties of copper cladded laminates (PCB). The results obtained from this is compared with two commercial software's namely Bcond and Lux PCB, which are meant for calculating the effective thermal conductivity.For different thickness of PCB the effective thermal conductivity is validated.

II. Mathematical formulation

A. *Effective Thermal Conductivity*

PCB is layered composite of copper foil and glass-reinforced polymer (FR4)

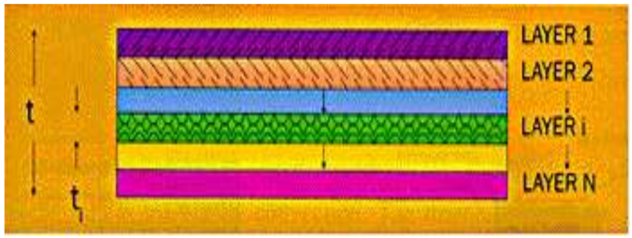

Fig. 1: Heat conduction in PCB

- Can treat this layered structure as homogeneous material with two different thermal conductivities
- Heat flow within plane is $k_{In\text{-}plane}$
- Heat flow through thickness of plane is $k_{Through}$

Conductivity Equations:

$$\kappa_{In-plane} = \frac{\sum_{i=1}^{N} \kappa_i t_i}{\sum_{i=1}^{N} t_i}$$

$$\kappa_{Through} = \frac{\sum_{i=1}^{N} t_i}{\sum_{i=1}^{N} t_i / \kappa_i}$$

Where, t is the thickness of the given layer and
K is the thermal conductivity of fiber

Even for thin copper layers, $k_{In\text{-}plane}$ is much greater than $k_{Through}$ .As FR4 has very low thermal conductivity, a continuous copper layer will dominate heat flow. Because of this, thermal conduction is not efficient where no continuous copper path exists.

If the orientation of fiber is considered in each layer then rotation operator is used to evaluate the effective thermal

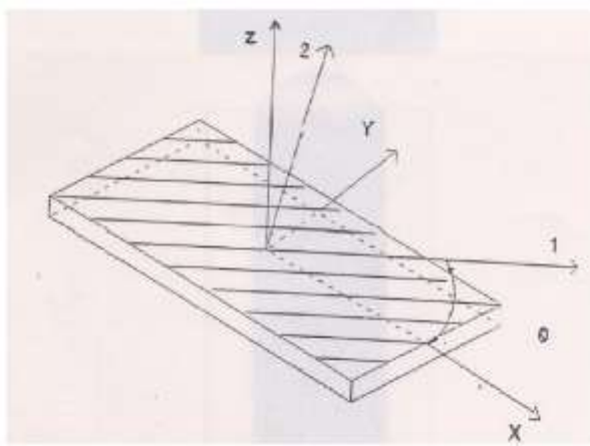

Fig. 2: Principal Material axes of a Lamina

Wherein,
1,2 and 3 (z) are three principal materials directions with:

- 1 : being the material fiber direction ;
- 2 is perpendicular to the material fiber direction and
- 3: is normal to the plane 1-2

and coordinate axes x, y and z are the global coordinate directions.

The material conductivity tensor for the lamina can be written as

$$K = \begin{bmatrix} k_1 & 0 & 0 \\ 0 & k_2 & 0 \\ 0 & 0 & k_3 \end{bmatrix}$$

The direction cosines of the two different systems 1-2-3 and x-y-z in matrix form is given as:

$$[P] = \begin{bmatrix} \cos(x,1) & \cos(x,2) & \cos(x,3) \\ \cos(y,1) & \cos(y,2) & \cos(y,3) \\ \cos(z,1) & \cos(z,2) & \cos(z,3) \end{bmatrix}$$

According to the lamination theory, wherein the material axis in thickness direction and coordinate axis in thickness direction are the same (plane stress), the direction cosine matrix becomes,

$$[P'] = \begin{bmatrix} \cos(x,1) & \cos(x,2) & 0 \\ \cos(y,1) & \cos(y,2) & 0 \\ 0 & 0 & \cos(z,3) \end{bmatrix}$$

By considering the orientation angleθ, this equation becomes

$$[P'] = \begin{bmatrix} \cos\theta & \cos 90 - \theta & 0 \\ \cos 90 + \theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

The transformation from the global coordinate axes (x,y,z) to material coordinate axis (1,2,3) is given by

$$\begin{Bmatrix} 1 \\ 2 \\ 3 \end{Bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} = \begin{Bmatrix} x \\ y \\ z \end{Bmatrix}$$

Then the conductivity of each lamina with respect to the global axes is given by

$$\begin{bmatrix} kxx & kxy & 0 \\ kxy & kyy & 0 \\ 0 & 0 & kzz \end{bmatrix} = [P']^T [K][P']$$

The effective thermal conductivity for a laminate according to the heat flows through a laminate in xy plane (Kxx and Kyy) and perpendicular to the laminate along z plane (Kzz) are given below

$$kxx^T = \frac{1}{tt}\sum_{i=1}^{N} kxx \bullet \text{tply}(i) \qquad kyy^T = \frac{1}{tt}\sum_{i=1}^{N} kyy \bullet \text{tply}(i)$$

$$kxy^T = \frac{1}{tt}\sum_{i=1}^{N} kxy \bullet \text{tply}(i) = kyx \qquad kzz^T = \frac{1}{tt}\sum_{i=1}^{N} kzz \bullet \text{tply}(i)$$

where,
tt is the total thickness of a laminate
tply is thickness of the lamina kxx^T, kyy^T, kzz^T are directional effective thermal conductivities along x, y, z direction respectively.
Kxy, kyx^T are the in-plane thermal conductivities in x-y plane.

B. Bcond AND Lux PCB

Bcond is a thermal conductivity calculation tool for PCB,s used for calculating the thermal conductivity of a laminated PCBs without taking considering the ply orientation.

- Where the input parameters are ;
- Thickness of each layer ;
- Material k value for each layer;
- Percentage of weight ;

Lux PCB is another software tool meant for the thermal analysis of board level problems. It uses finite element approach for getting the temperature results. To calculate the effective k value of the stacked layers in printed circuit board, we should enter the board material along with thickness and conduction layers should enter in the pcb stack up information. After entering all input values it will give the effective thermal conductivity values.

III. RESULTS AND DISCUSSIONS

The analytical results are validated against the Bcond and LuxPCB tools. For different layer thickness the effective thermal conductivity values are compared.

A. *Case1:*

A laminated composite material consists of epoxy as board material and upon with copper layers is added.

Table – 1
Epoxy with 10 layers of copper

Material	*Thermal Conductivity (w/m-k)*	*Thickness (mm)*	*No of layers*
Epoxy	*0.29*	*5*	*1*
Copper	*398.16*	*0.03556*	*10*

Results: the results of effective values obtained are compared below.

Table – 2
Effective thermal conductivities in (W/m-K)

	Kx	*Ky*	*Kz*
Lux PCB	*28.584*	*28.584*	*0.312*
Bcond	*27.000*	*27.000*	*0.310*
Laminate Code	*26.705*	*26.705*	*0.310*

B. *Case2:*

In this problem the base material of epoxy is used of the same thickness but 3 copper layers are added on it

Table – 3
Epoxy with 3 layers of copper

Material	*Thermal Conductivity (w/m-k)*	*Thickness (mm)*	*No of layers*
Epoxy	*0.29*	*5*	*1*
Copper	*398.16*	*0.03556*	*3*

1) *Results:*

Table – 4
Effective thermal conductivities (W/m-K)

	Kx	*Ky*	*Kz*
Lux PCB	*8.7783*	*8.7783*	*0.296*
Bcond	*8.700*	*8.700*	*0.30*
Laminate Code	*8.609*	*8.609*	*0.296*

C. *Case3:*

The payload support structure consists of CFRP cylinder (payload cylinder) where layup sequence is given. The details of properties are given below.

Table – 5
Material properties (thermal) at the ply-level for the payload CFRP cylinder along with the ply lay-up sequence

Sl no	*Component*	*Property details*
1	*Thickness*	*0.125 mm (each layer)*
2	*No. of layer*	*15*
3	*Lay-up*	$90_2/-60/60_2/-60/90_3/60/-60_2/60/90_2$
6	*kxx*	*4.2 w/m- k*
7	*kyy*	*0.7 w/m- k*
8	*kzz*	*0.7 w/m- k*

1) *Results:*

Table – 6
Effective thermal conductivities (W/m-K)

	Kx	*Ky*	*Kz*
Calculated	*3.730*	*1.167*	*0.700*
Laminate Coded results	*3.733*	*1.166*	*0.700*

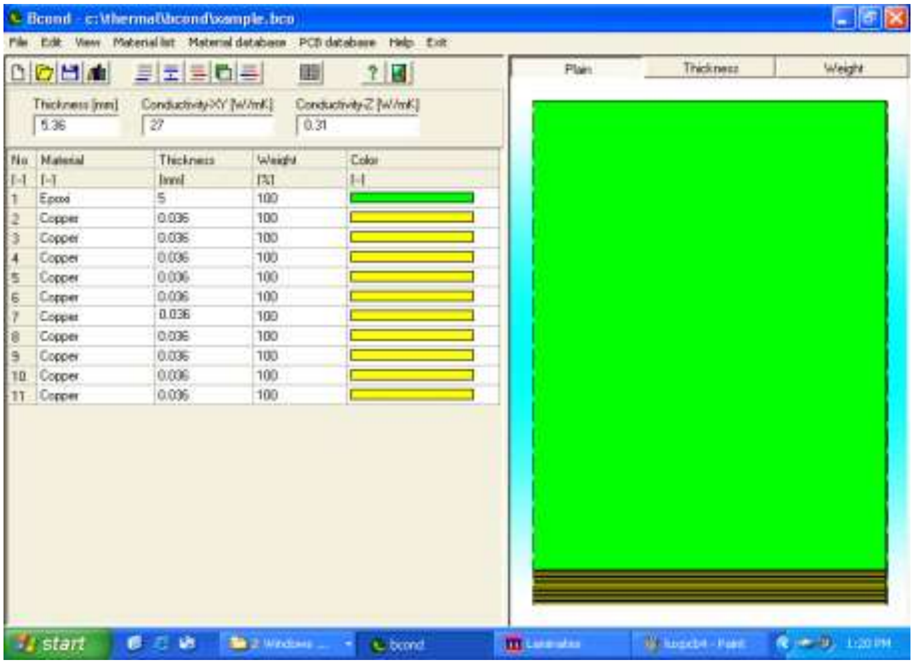

Fig. 3: Bcond for 10 layers of copper

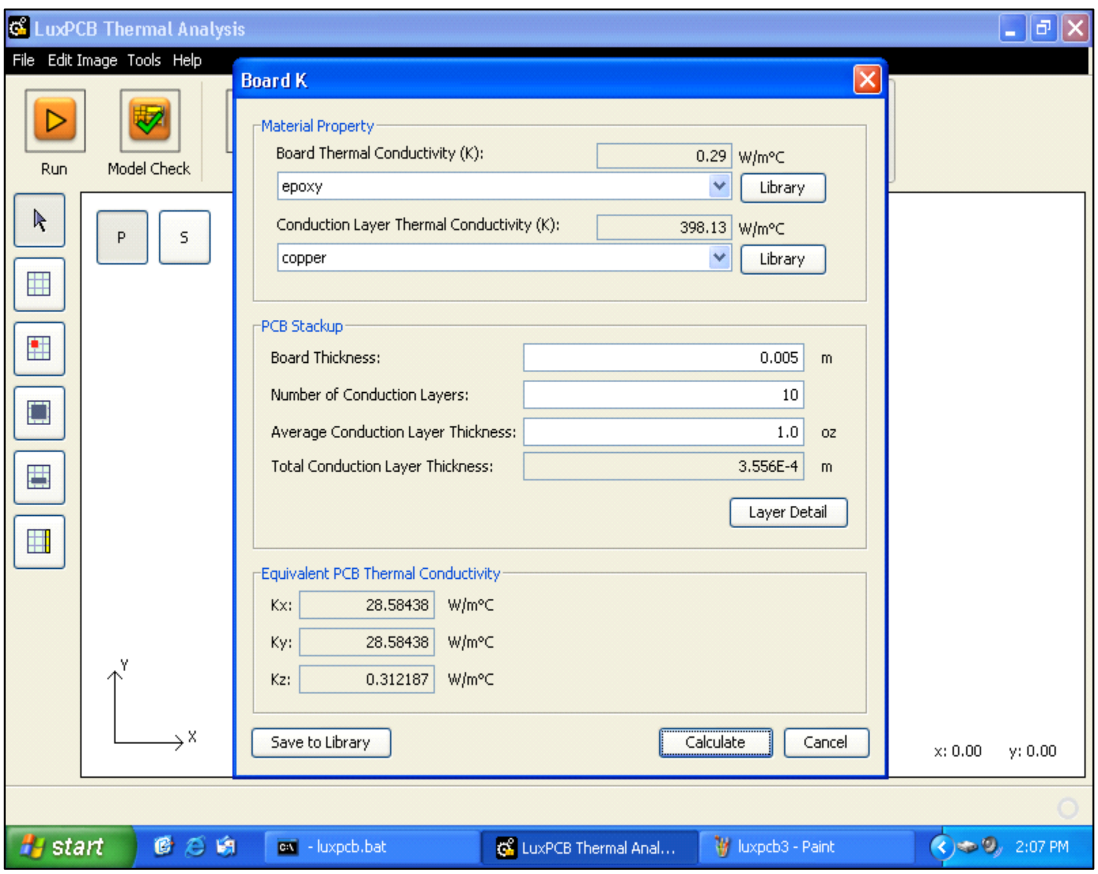

Fig. 4: Lux PCB for 10 layers of copper

IV. CONCLUSIONS

The effective evaluation of thermal conductivity value is an important property in the conduction heat transfer of PCB. Since conduction heat transfer is directly proportional to thermal conductivity according to Fourier Law.

For the first two problems, orientation of ply is not considered but in 3rd problem the orientations are considered with each layer. The analytical results are compared with the results obtained from tools BCOND and LUXPCB. These effective values can be used for the thermal analysis of Board level problems.

An algorithm is to be employed and code should be written in FORTRAN or C++ language which should be employed for calculation of Effective thermal conductivities values where these values will be in good approximation with the software results, can be considered as a future work.

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