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Thermal Analysis Of An Electronic Package Using TAMS And TNETFA

[1]Nataraj K A
M.Tech, Student, Mechanical Department
Siddaganga Institute of Technology
Tumkur, Karnataka

[2]S Ganesan
Scientist-SG, Thermal System Group
ISRO Satellite Centre
Bangalore, Karnataka

[3]K V Sreenivasa Rao
Professor, Mechanical Department
Siddaganga Institute of Technology
Tumkur, Karnataka

Abstract

A typical electronics package is verified using the lumped modeling methodology using the FORTRAN code TNETFA and TAMS available in academic literature. TAMS stand for Thermal Analyzer for Multilayer Structures (TAMS) and TNETFA stands for Transient Network Thermal Analyzer (TNETFA). Electronics packages constitute dissipation heat sources of components located on multi-layered boards (PCB). Protecting the components from thermal damage which comes from careful selection of layout, dissipation levels and thermal control methods. Code implementation, code verification, academic benchmarks and board level validations has been made to validate the applicability of TAMS and TNETFA codes for PCB thermal analysis. Results of the thermal analysis are compared with standard benchmarks in available literature. While considering the strong conduction and radiation modes under typical operating environments, improvements in the temperature levels of the PCB & Components were observed. Based on the results of thermal analysis changes are suggested to improve thermal performance of the electronic package.

Keywords-***TAMS, TNETFA, Electronic package, PCB, Chip,*** Lumped Modeling

I. INTRODUCTION

Power dissipation is an important issue in present day PCB design. Power dissipation will result in temperature difference and pose a thermal problem to a chip. In addition to the issue of reliability, excess heat will also negatively affect electrical performance and safety.

Circuit boards are often called printed circuit boards or PCB's. The modern manufacturing process is however based on etching not printing. The simplest PCB has one or two layers of copper. They are typically used in low cost home electronics. High performance products require more complex layer structures. The only areas where copper has been etched away are where via holes connect signals from one layer to another. A PCB usually serves three functions.

1. Provides the necessary mechanical support for the components in the circuit.
2. Necessary electrical interconnections.
3. Bears some heat load from all the components which it carries.

Various components are placed on the PCB with different power sources. Many different types of components are involved covering various shapes and electrical lead wire arrangements. Generally used components are discussed below. Dual inline packages (DIP'S), large scale integrated circuits (LSIC's), hybrids and most recently the micro processes have been replacing the discrete resistors, capacitors, transistors and diodes. No matter which groups of components are used for an electronic system, the mounting techniques must provide sufficient cooling to permit the device to operate effectively in its environment. The best method of determining the effectiveness of any cooling system appears to be in the **measurement of the case and junction temperatures** of the individual electronic components. Experience has shown that it is not a good practice to exceed the case temperature of **100 degree centigrade** for long period on electrically operating equipment's with any of the components mentioned above, or the failure rates show a large increase when the electronic components are to be cooled only by conduction. A good heat flow path must be provided from each component to the ultimate heat sink. The ultimate heat sink may simply be the outside ambient air, or it may also be a sophisticated liquid cooled heat exchanger. Each segment along the heat flow path must be examined in detail to ensure that the thermal resistance is low enough for the proper cooling.

II A.TAMS (THERMAL ANALYZER FOR MULTILAYER STRUCTURES)

TAMS is written in FORTRAN IV in a manner that permits the program to be run on most computing systems with at least 30,000(decimal) words of memory. The equations derived for sources and resistances at various levels within the multilayer structure have been included with present values of depth that meet the requirements of most practical problems.

Application of TAMS requires the user to select from one of six possible cases, any of which may use anisotropic thermal conductivity.

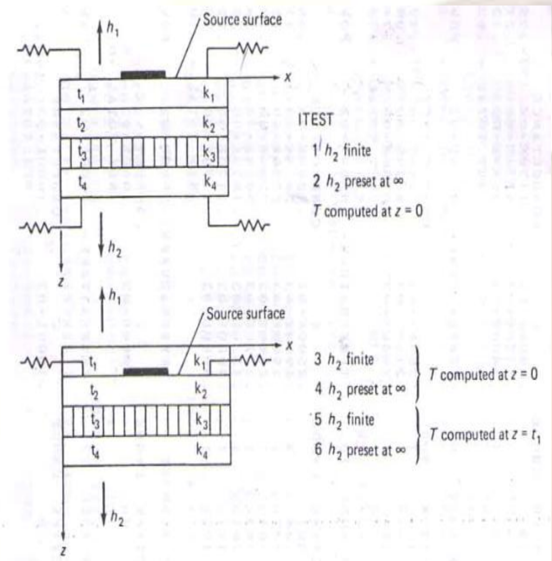

Fig 1. Problem cases for TAMS

The above figure emphasizes the multilayer aspect. Cases 1, 3 and 5 are concerned with Newton's law cooling from both the surfaces, whereas cases 2, 4 and 6 assume an isothermal surface (T_A) at the base. In all the cases except 3 and 4, the temperatures are calculated at the source centers and in the same plane as the sources. The two exceptions, cases 3 and 4, still provide the temperature calculations at the x, y centers of the source, but displayed in the z-direction to the top surface (z = 0). The use of resistances attached to the bottom surface (z = C4) is limited to case 1, sufficient for most problems.

II B. TNETFA (Transient Network Thermal Analyzer)

TNETFA is a general purpose steady state and transient thermal analysis program that may be used to predict temperature pressure and airflow. Although the program is not difficult to use, the engineer or designer will have to spend some time to develop familiarity we basic input rules and features peculiar to this program.

A thermal network analysis requires a theoretical model that provides a one to one correspondence between the physical and mathematical models. As in all simulation techniques, the theoretical model is in reality an approximation of physical model. A successful thermal analysis requires the correct identification of significant aspects of the physical system that must be individually incorporated into theoretical model as conductance elements. The geometry of some heat transfer and air flow problems is sufficiently complex that the analyst may be able to include only the most significant flow paths.

Each element of the thermal model must be quantitatively specified. In a conduction problem a path length, cross sectional area and thermal conductivity are required to complete specify a single element. A convectively cooled surface must be described by a surface element area and a heat transfer coefficient. Accurate values of heat transfer coefficients are particularly difficult to obtain because complex and irregular shapes give rise to airflow and heat transfer characteristics that are often quite different often what is predicted using classical heat transfer criteria.

A few comments are in order concerning airflow predictions. Two techniques are indicated in this Article. The first uses classical methods to predict pressure and airflow distribution within an electronic enclosure. TNETFA permit solutions of pressure network problems to o complex for scientific calculator solutions. Occasionally it is necessary to have both laminar and turbulent flow resistances in a single network and TNETFA will accumulate this kind of problem.

A second analytical tool available for airflow characterization uses two-dimensional laminar flow theory. Air velocity and temperature rise may be computed from streamline computations. This method is most valid for forced airflow, and accuracy of the results dependent upon the extent to which the actual airflow is of streamline nature. There are very few data at present to indicate the accuracy of this method other than qualitative-type indications of potential trouble spots.

THEORITICAL BASICS OF TAMS AND TNETFA

The equation requiring a solution is the differential equation for steady state heat conduction with an anisotropic thermal conductivity K_{xi}, K_{yi}, K_{zi} independent of x, y, and z respectively within each layer.

$$\mathbf{K_{xi} (\Delta^2T/ \Delta x^2) + K_{yi} (\Delta^2T/ \Delta y^2) + K_{zi} (\Delta^2T/ \Delta z^2) = -Q}$$

BOUNDARY CONDITIONS:

The most applicable edge boundary conditions on T(r) assume negligible heat loss across these usually small areas:

$$\Delta T/\Delta x = 0;\ x=0,\ A$$

$$\Delta T/\Delta y = 0;\ y=0,\ B$$

Radiation and convection from either or both of the substrate surfaces are accounted by:

$$K_z\Delta T/\Delta z - h_1 T = 0;\ Z = 0$$

$$Kx\Delta T/\Delta z + h_2 T = 0;\ Z = C4$$

Where, h_1 and h_2 are the appropriate heat transfer co-efficient. As isothermal at Z= C4 is obtained in the final solution by letting h_2 approach infinity. Note that the surface flux density is written as having linear temperature dependence.

SOLUTIONS FOR MULTI SOURCES

The theoretical considerations of extending the single-source solution to the significantly more practical problem of a multi-source, multiple lumped resistance application are accomplished by super position of the single source solutions.

$$T(r_i) = \sum_{j=1}^{NS} Q_j A_{ij}(r_i, r_j) - \sum_{k=1}^{NR} F_k A_{ik}(r_i, r_k) + T_A$$

Multi-source, multi resistance temperature

The A_{ij} and A_{ik} are solution for single source magnitude; i.e., A_{ij} is the temperature $T(r_i)$ at r_i due to a unit source at r_j for zero ambient temperature. Q_j is the heat into the system at r_j and F_k is the heat out of the system at r_k and through a lumped parameter thermal resistance R_k.

SCOPE OF WORK

The existing literature on PCB thermal analysis suggests lumped thermal model development and open source codes like TAMS and TNETFA can help the user to solve academic and reasonably sized board level thermal problems.

In this work, the source codes of TAMS and TNETFA have been made use of to create, validate a series of problems and also understand its results with the commercially available tools like TAK, PC-Analyze and FEAP software's

TAMS PROGRAM ACCURACY

The accuracy of a particular solution is dependent upon at least three factors.

- The first is the extent to which the physical problems and TAMS model have one to one correspondence. Certainly this is difficult to assess quantitatively.
- Second, the basic physical parameters, thermal conductivity and heat transfer coefficients, are very often known to no better than +_ 20%.
- A third element addressed is the error obtained by truncating the Fourier-series to a finite number of terms.

TAMS does not have a self-contained series truncation system, but rather the user resorts to a program option that outputs a single-source plot of temperature vs number of terms.

II. PROBLEM DEFINITION AND ENCLOSURE DETAILS

The current package consists of a PCB with number of components having different level of heat dissipations. Each PCB is conductively and radiatively coupled for heat transfer. With the modes of heat transfer being conduction, convection and radiation. The aim of the present work is predicting the steady state temperature of a PCB. Effects due to various thermal parameters of the components are studied and analyzed.

The enclosure and board properties in detail required to carry out the problem. A printed circuit board is 9.0inX9.0in in dimension and 0.5in thick. A realistic problem with 34 components with a total power dissipation of 19.37W is taken, solved and analyzed. The component details are given in the table below. Both one resistor and two resistor models are solved using TNETFA tool.

BOARD PROPERTIES

Name: sample card
Type: PCB
Material: FR4
Thermal conductivity: 0.00686W/in deg C
Board emissivity: 0.9
Total power: 19.57W
Length: 9.0 in
Width: 9.0 in
Thickness: 0.5 in
Node size: 10X 10
Initial temperature: 51 deg C
Natural convection dimensional parameter: 1.6667
Resistor type: 1 and 2 resistor.
Component style: Dual inline package (DIP)
Number of leads: 8.
Lead cross section area: 4.52 X E-4 in^2.
Lead length: 2.04E-1 in

Lead material: Kovar.
Lead thermal conductivity: 3.95E-1

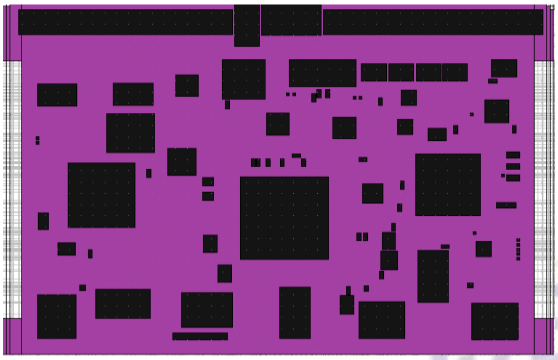

Fig2. PCB with components

ENCLOSURE PROPERTIES

Type: Hallow tray type
Total power: 0W
Length: 10in
Width: 10in
Height: 10in
Temperature: 51^{o}C
Thermal conductivity: 0.26021W/in^{0}C
Wall thickness: 0.5 in

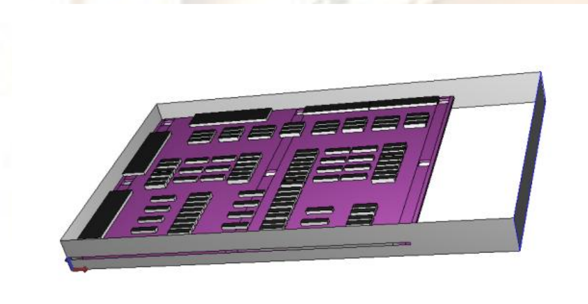

Fig 3. PCB in an enclosure

COMPONENTS DETAILS

SOURCE	POWER (W)	X-PCB (in)	Y-PCB (in)	LENGTH (in)	WIDTH (in)	HEIGHT (in)	R_{jb} (^{0}C/W)	R_{jc} (^{0}C/W)
1	4.0	2.413	7.086	1.1328	1.137	0.16	1.2	1.2
2	2.3	1.833	3.82	1.47	1.48	0.16	12.1	0.19
3	2.0	3.33	6.05	0.487	0.487	0.16	17.6	7.34
4	1.83	2.61	1.239	1.1036	1.092	0.16	17.4	7.8
5	0.825	1.082	1.78	0.9296	0.5232	0.16	82	18
6	0.75	3.98	3.34	0.386	0.3912	0.16	20.9	20.5
7	0.75	4.05	4.475	0.386	0.3912	0.16	20.9	20.5
8	0.75	4.75	6.014	0.3830	0.386	0.16	20.9	20.5
9	0.75	0.7927	7.75	0.518	0.9144	0.16	95	20
10	0.75	0.7927	6.837	0.518	0.9144	0.16	95	20
11	0.75	0.4366	4.119	0.9144	0.5232	0.16	95	20
12	0.6	0.4165	0.607	0.607	0.650	0.16	50	50
13	0.45	0.4368	2.529	2.5296	0.645	0.16	50	50
14	0.45	0.4368	8.087	8.087	0.7747	0.16	50	50
15	0.396	3.7388	7.625	7.625	0.6654	0.16	82	18
16	0.396	3.7388	6.76	6.7612	0.6908	0.16	82	18
17	0.33	4.26	0.762	0.762	0.4064	0.16	53.3	24.7
18	0.315	4.582	2.324	2.324	0.264	0.16	52	4
19	0.26	3.688	5.354	5.354	0.264	0.16	52	4
20	0.26	3.56	5.74	5.74	0.264	0.16	52	4
21	0.167	0.167	5.436	5.436	0.6146	0.16	84.04	18.2
22	0.165	3.952	1.818	1.818	0.2214	0.16	104	38
23	0.16	4.064	2.38	2.38	0.264	0.16	52	4
24	0.033	4.582	6.78	6.78	0.3911	0.16	104	38
25	0.033	4.582	7.457	7.4572	0.3911	0.16	104	38
26	0.033	4.572	8.74	0.3911	0.6704	0.16	104	38
27	0.033	4.572	8.07	0.3911	0.6704	0.16	104	38
28	0.017	1.442	5.45	0.3048	0.232	0.16	113	46.6
29	0.033	2.89	5.76	0.142	0.1828	0.16	206	86
30	0.033	3.147	5.76	0.1472	0.1828	0.16	206	86
31	0.033	5.01	2.37	0.3073	0.4267	0.16	73	24
32	0.033	5.01	1.46	0.3073	0.4242	0.16	73	24
33	0.033	5.01	1.91	0.3073	0.4216	0.16	73	24
34	0.033	5.01	2.83	0.3073	0.4318	0.16	73	24

CASE 1: ONE RESISTOR MODEL RESULTS FROM TNETFA vs TAK

COMPONENT (DIP-8 PINS)	TNETFA (Deg C)	TAK (Deg C)	COMPONENT (DIP-8 PINS)	TNETFA (Deg C)	TAK (Deg C)
1	90.0	92.33	18	81.07	83.2
2	68.71	71.15	19	82.67	84.2
3	140.5	142.0	20	82.71	82.07
4	74.0	76.34	21	45.52	46.04
5	76.98	78.26	22	68.05	70.17
6	74.86	76.2	23	73.33	75.4
7	88.51	90.99	24	66.68	69.86
8	74.96	77.6	25	60.96	62.43
9	68.6	70.0	26	51.61	50.82
10	87.80	90.42	27	36.12	36.41
11	88.16	90.08	28	57.92	59.70
12	60.73	61.55	29	70.72	70.21
13	63.87	65.0	30	75.55	76.06
14	63.67	65.7	31	43.78	44.78
15	78.64	80.2	32	42.19	43.09
16	88.56	90.12	33	42.25	43.20
17	60.81	61.55	34	42.99	44.03

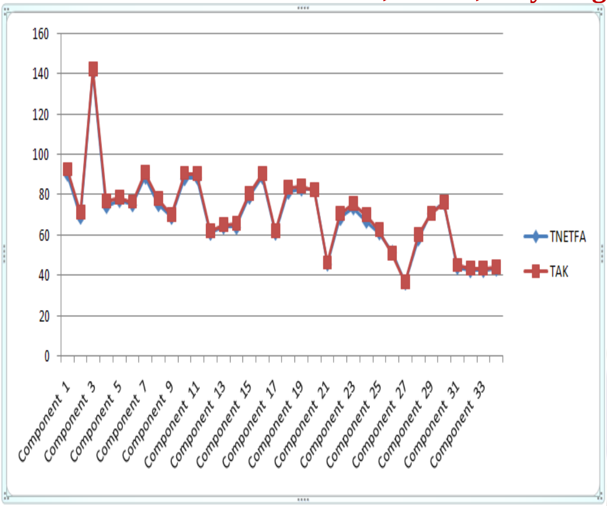

Fig 4 Graph plot for 1-resistor model, TNETFA vs TAK

CASE 2: TWO RESISTOR MODEL RESULTS FROM TNETFA vs TAK

COMPONENT (DIP-8 PINS)	TNETFA (Deg C)	TAK (Deg C)	COMPONENT (DIP-8 PINS)	TNETFA (Deg C)	TAK (Deg C)
1	86.21	88.16	18	78.25	80.18
2	65.23	67.25	19	78.73	80.79
3	133.5	135.98	20	78.77	80.09
4	70.30	72.00	21	43.62	44.186
5	72.94	74.95	22	65.40	67.23
6	71.97	72.3	23	70.64	72.53
7	85.57	87.7	24	62.16	64.93
8	72.06	74.2	25	56.73	57.85
9	65.64	66.66	26	48.18	47.8
10	81.47	82.33	27	35.51	35.7
11	81.75	83.00	28	55.05	56.4
12	57.54	59.08	29	67.19	69.25
13	59.92	61.00	30	71.52	73.6
14	60.48	62.21	31	42.59	43.46
15	73.27	75.04	32	41.17	41.95
16	80.73	82.79	33	41.27	42.09
17	59.02	60.45	34	41.99	42.87

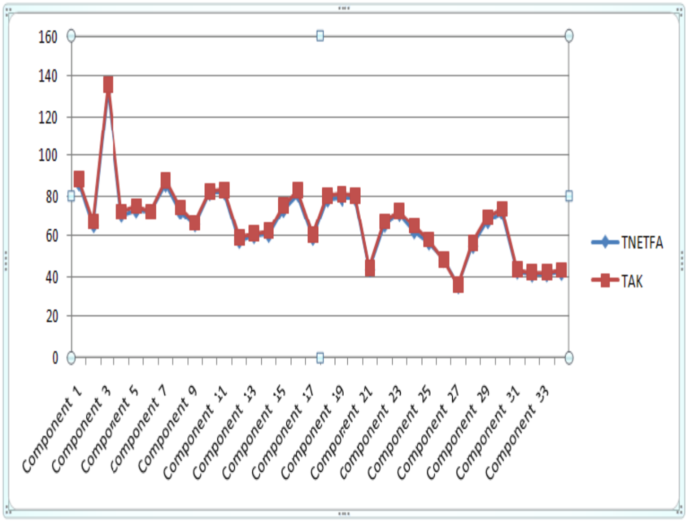

Fig 5 Graph plot for 2-resistor model, TNETFA vs TAK

III. CONCLUSION

The open source codes of TAMS and TNETFA were compiled and tested with a series of verification problems. The difficulty in using them from manually prepared data files was realized while solving larger problems. So, suitable GUI interfaces with data validation were developed as a part of this study. An enclosure housing a typical PCB with several components was thermally analyzed using the above tools. Their results from a commercial tool like TAK were also compared. A good match in results was noticed for the problems attempted in this project. The analysis carried out using TAMS and TNETFA could provide useful insight into the thermal behavior of an electronic package.

An effective thermal modeling and analysis solver can provide considerable ease in thermal analysis of an electronic package and its components. Such solver can provide the analyst a mean to evaluate design alternatives towards evolving better thermal management schemes. Thermal performance levels in terms of temperatures can be accessed under different operating conditions and safe operating levels can be specified for operation of any electronic package.

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