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THERMAL ANALYSIS OF PRINTED CIRCUIT BOARD (PCB) OF AVIONICS EQUIPMENT

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ABSTRACT

As the power requirements of advanced aircrafts steadily move towards higher density and higher heat loads, Requirements of thermal analysis for advanced avionics are becoming more severe and critical to avionics design year after year. So increasing the power densities in compact electronic systems or in high density packages has escalated the need for proper thermal analysis. Power electronics devices for future advanced aircrafts require higher performance at the same time more compactness. Though this trends a great increment of the power density per square inch of PCB's, the operating temperature of most of the devices is still settled below 125^{O}C. An accurate prediction of the junction temperature of components is necessary for confidence in their reliability and performance. The task of thermal designer of an electronic system is to design a cooling system that will keep the junction temperature of the key components below a prescribed value. Since this usually involves a number of iterations the designer therefore relies heavily on analytical tools to predict the critical temperatures. In this paper , thermal behavior of highly heat dissipating components, temperature distribution on the board, Junction temperature are to be analyzed using PCB thermal analysis software, taking total heat dissipation of components, board properties, grounding and metal core properties into consideration. With these analysis results we can foresee any problem arising due to inadequate provision for heat dissipation resulting in poor performance & reliability and ultimately failure of the components and equipment.

Nomenclature: P = Total Power dissipation (W), T_c= Component Casing temperature (^{o}C)
T= Component Junction temperature (^{o}C), θ_{jc} = Junction to Case Thermal Resistance (^{o}C/W),
θ_{ja} = Junction to Ambient Thermal Resistance (^{o}C/W) , K = Thermal Conductivity (W/mk) ,
MVF = Metal Volume Fraction

1.Avionics Equipment for Aircrafts and Missiles:

Electronic LRU (Line Replaceable Unit) used in Aircrafts and missiles often have odd shapes that permit them to make maximum use of the volume available in tight spaces. Since volume and weight are critical, the electronic LRUs have a high packaging density. This value normally ranges from about 0.03 lb\in^3 to 0.04 lb\in^3 depending upon the environmental requirements. The weight of a typical electronic LRUs will range from about 10lb to 80lb. The vibration frequency spectrum for aircrafts will vary from about 20Hz to 2000Hz, with acceleration levels that can range from about 1g to 10g peak. The highest accelerations appear to occur in the vertical direction in the frequency range of about 100Hz to 4000Hz. The lowest accelerations appear to occur in the longitudinal direction, with maximum levels of about 1g in the same frequency range. he vibration environment in supersonic aircrafts and missiles is actually more random in nature than it is periodic. As the forcing frequencies in aircrafts and missiles are so high, it is virtually impossible to design resonance free electronic systems for these environments. The forcing frequencies present in aircrafts and missiles will excite many resonant modes in every electronic LRU. Therefore, care must be taken in design and analysis of an electronic system or it can dynamically tune with respect to the electronic component to prevent coincident resonance that can lead to rapid fatigue failures.

The main causes of failure of equipment in the field are environmental parameters such as vibration, humidity, dust and Temperature. It is worth mentioning here that 55% of the avionics failure is caused by the undesirable rise in temperature and this is mainly due to bad Thermal design. Thumb rule says, "The life of an electronic

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device reduces by half for every 10^0C rise in its operating temperature". It becomes therefore essential to keep the temperature rise of the electronic device/equipment under control for reliable operation for a longer period. Thermal design today is a major limiting factor for performance of avionics equipment.

Thermal VIAS : In printed circuit board design, VIA refers to a pad with a plated hole that connects copper tracks from one layer of the board to other layer(s). Either the holes are electroplated or small rivets are inserted. High-density multi-layer PCBs may have **blind VIAS**, which are visible only on one surface, or **buried VIAS**, which are visible on neither (example image of each). In integrated circuit design**,** a **via** is a small opening in an insulating oxide layer that allows metallic interconnect on different interconnect layers to form a connection. A via on an integrated circuit is often called a through-chip.

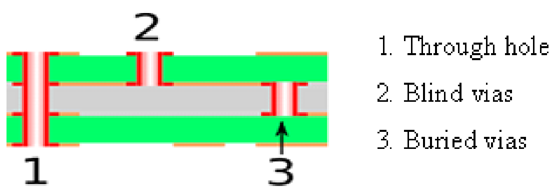


Fig 1. Pad with a plated hole that connects copper tracks from one layer to other layers

2.Thermal analysis of PCB:

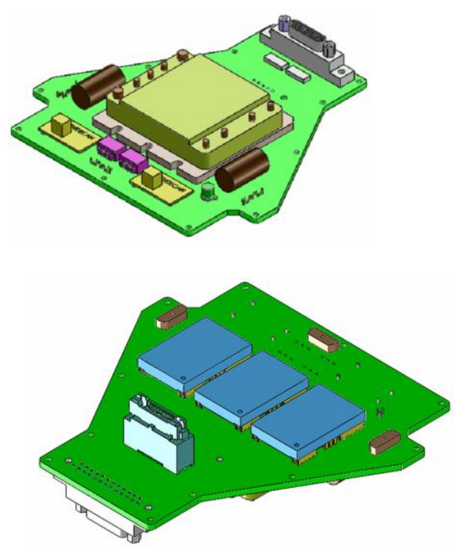


Fig2. PCB Top View and Bottom View

The Printed Circuit Board (PCB) of Avionic Equipment will be supplied with input of 28V & 2 Amp from missile. From there it will generate an output of +7V & 3Amp, +5V & 8Amp, -5V & 1Amp and +12V & 0.5Amp supply to various sub systems of the unit. It is an 8 layered PCB of irregular shape with dimensions 124x117.5mm. The board is located inside a closed enclosure, heat transfer occurs through conduction and radiation rather than convection. So the PCB is conduction cooled board with the PCB edges resting on the aluminum metal chassis, grounding and tightened with M2.5 screws to the chassis at various locations for better dissipation. And it is provided with a special screw with circlip for easy removal.

PCB material : FR-4 (Cu cladded glass epoxy laminate)
:
K=0.3 W/m K
Thermal layer material : Copper (Thickness 0.1, 0.2mm)
:
K=394 W/m K
Total heat dissipation : 20 Watts

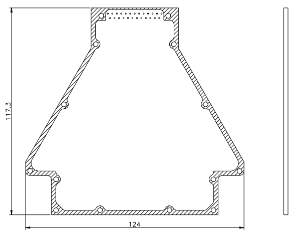


Fig. 3 Mechanical layout of the PCB

The above figure 2 shows the mechanical layout of the PCB, the hatched portion (2mm all around the edges) indicates the grounding (Copper) on the board from top layer to the bottom layer.

Total volume of the board = 15382 mm^3 (for 1.6mm board) = 23073 mm^3 (for 2.4mm board)

Volume of default metal traces in the board = 460 mm^3 (for 1.6mm board) = 962 mm^3 (for 2.4mm board)

For a typical board of 1.6mm thickness, the default metal trace in the board is about 3%.

3.Heat source: Whenever current flows through a resistant element, heat is generated in that element. There are many components in the electronic circuit that are operated by flow of current only. All the electronic components start functioning during its performance. No component has 100% efficiency. Therefore the amount of inefficiency will be generated as heat. The magnitude depends on the functionality of individual.

The Printed Circuit Board (PCB) generates maximum heat compared to other modules as it is the source of power to all the sub systems. The location of the components is also important as it may yield higher temperatures. It is safe to place two heat generating components apart rather than placing nearby. Proximity of other equipment may cause the heat generation through radiation. The main heat sources are

- Integrated circuits
- Power amplifiers
- MOSFET
- Diodes
- Inductors
- Transformers
- Transistor
- Capacitor
- Resistor
- Oscillators

If this heat is not dissipated efficiently, the resulting high temperatures not only alter the output signals but also damage components, hence the system. The heat dissipation of two types of components is the most critical. They are the ones with high power and those of small sizes. The former ones give off much heat and could be very hot the latter ones have high power per surface area and also can be very hot. Therefore proper analysis of electronics PCBs is necessary to predict the problems arising and find the proper means to rectify them for better performance of the system. All major heat dissipating component details which are considered for analysis such as component designation, name, part no., power dissipation, junction temperature, casing temperature along with dimensions are given in the **table. 1**

4 Theoretical Results

The scope of this analysis is confined to Printed Circuit Board (PCB) Of Avionic Equipment and has been carried out by simulating environment conditions to which The PCB is subjected to and with appropriate boundary conditions.

4.1 Analysis Tool

BETA-soft is a thermal analysis program for Printed Circuit Boards (PCBs). This program uses three-dimensional modeling for complex air convection, conduction, and radiative heat transfer. Customers worldwide have validated the program's high level of accuracy. It is user friendly and has a fast accurate computation.The BETA-soft program performs a detailed analysis of the air convection from the pins and the thermal conduction through component sides, pins and the bottom air gap to the board. The heat transfer properties of the board are evaluated by considering all the layers of materials across the board thickness. Environmental conditions must be controlled to perform an accurate thermal analysis of a PCB design.The numerical scheme in BETA-soft uses advanced finite difference methods with adaptive grids which generate locally refined meshes automatically to resolve mismatching between board meshing and component shapes. Its advantage over the finite element scheme is its superior analysis speed at the same accuracy. BETA-soft achieves a speed factor about 50 times faster than traditional finite element approaches. Typical computation time for a board of 100 components on a PCB is 5 seconds.Beta-soft board reveals the board temperatures and gradients, component and junction temperatures, and the amount they exceed their respective limits. The software supports space, avionic, defense, telecom, and computer, automatic, medical, instrumentation and power supply industries. An accuracy of 10% has been constantly validated by the users.

Automatic interfaces with IDF, PADS, MENTOR, ALLEGRO, ORCAD, CADSTAR, VISULA, PCAD and much other ECAD software. Colorful temperature and gradient maps create output that is easy to read.Beta-soft can evaluate boards of multilayer and rectangular and circular shapes. The board can be placed at the edge or the interior of a cabinet, anchored by screws to heat sinks, cooled through wedge locks at the edges, in a sealed compartment, or in an open system with forced convection. The flow field can be natural or forced convection, and closed system can be cooled by heat exchangers. Effects of gravity, air pressures, and flow directions are modeled. Daughter boards, heat sinks, heat pipes, chip fans, and conduction pads can be attached to components. Some of the important terms which are used in Beta-soft

4.2Junction Temperature Limit:

The limiting temperature set for the junction of a component. If this limit is exceeded, it will be displayed in the Excess Temperature Screen. This may be specified in the "Board-Property" menu for default of all components or may be set uniquely to particular components in the "Library-Working" menu. It is represented by T_j.

4.3.Casing Temperature Limit:

The limiting temperature set for the casing of a component. If this limit is exceeded, it will be displayed in the Excess Temperature Screen. This may be specified in the "Board-Property" menu for default of all components or may be set uniquely to particular components in the "Library-Working" menu. It is represented by Tc.

4.4.Junction to Casing Thermal Resistance:

Also known as the $\boldsymbol{\theta_{jc}}$ value, this is the junction-to-casing thermal resistance for the component or package, measured in ^{o}C/Watt. This value will be provided by the manufacturer of the component.

$$\boldsymbol{\theta_{jc} = T_j\text{-}T_c/P}$$

4.5.Sink to Air Thermal Resistance:

This input is necessary if a heat sink is added to component. $\boldsymbol{\theta_{ja}}$ is the thermal resistance between a heat sink and the air when the heat sink is applied to a component. This value is a function of air velocity, usually provided by the manufacturer of the heat sink.

$$\boldsymbol{\theta_{ja} = T_j\text{-}T_a/P}$$

4.6Excess temperature:

Excess temperature is the junction and casing temperatures of components against their limits. Excess temperature will indicate how much each casing and junction temperature has exceeded their respective limits. The general default limits are set in the Board-Property menu.

4.7Thermal Resistance of Wedge Lock:

The wedge lock applied to the edge of board has a thermal resistance between the edge of the board and the heat sink. The typical unit is ^{o}C-in/watt.

4.8 Metal volume fraction:

Metal volume fraction is the average volume fraction of metal in the board at a particular location. This is the fraction, by volume of the metal in the board itself. For a printed wire board, this value is usually on the order of 0.01. In general this value is lower than 0.07 for a board of 1.6mm thickness. If a metal plate or ground plane is used on the board, the metal plate volume has to be included in this value.

4.9 Default metal traces in the board:

This value is the nominal or default percent of metal traces in the board. The default metal volume fraction is usually 1% to 3% for an average PCB with no ground plane or metal core. For a typical board of 1.6mm thickness and 1 oz copper, the metal volume fraction is about 3%.

4.10 Thermal Vias:

Thermal vias are similar to conventional vias but they are placed to enhance the conduction across the board locally. This option will be used to calculate the metal volume fraction in an area containing thermal vias. In general the inside of the vias is filled with solder. Terminology of via is: The "outside diameter of the via" is the total diameter including the outer rim and the filler. The “thickness of the plating near the outside diameter of the via” is the thickness of the plating on only one side. The relation is, diameter of the filler + (2x thickness of the plating) = total outside diameter of the thermal via.

4.11 Board thickness:

The sum of the three values (layer 1, lyaer2 & layer3) is the measurement of the board thickness in the Z direction. These values may be recorded in inches or millimeters. We have to set up 3 physical layers for a board. For a conventional PCB with multiple layers, one physical layer is enough to represent all of them and the thickness of 2nd and 3rd layer can be set to zero. For boards with metal cores, 3 layers are recommended. We have the option of choosing the 2nd layer with a different material from the other 2 layers. For special applications (frequently on military and Avionic systems), two PCBs are attached from each side of a thick metal plate to allow for effective heat conduction to the wedge lock at edges. Since the metal plate could be a different material, BETA soft recommends the use of 3 layers in this type of modeling with layer 2 being the metal plate

4.12 Metal core:

Metal is embedded in between the layers of the PCB as one of the layer to improve the heat dissipating capability of the board. The metal layers are connected through the plated through holes through which the heat will flow. In general aluminum, copper-invar-copper, copper metals are used in metal core PCB’s.With aluminum metal core PCB’s there is a chance of delaminating at the interface of the two metals because of the mismatch in the coefficient of thermal expansion and its thermal resistance is relatively high. With copper-invar metal core PCB’s the thermal resistance is very low where as it is very Expensive. With copper metal core PCB’s thermal resistance is low and it is also effective, cheap when compared with copper-invar metal core

5 Software Interface and Model Creation

The BETA-soft program can be used with and without a CAD interface. If CAD file is not available, we can simply make our own board, and place the components from the master library or we can create our own components manually. Boards with 20 to 30 components take very little time to place on the board manually.

If the number of components are more than 50 it is better to import the PCB file directly from ECAD interface. The board placement file will be extracted through the ECAD interface program, and will automatically be loaded into the BETA-soft program when the file is opened.

In the present analysis the model is directly imported from CADSTAR ECAD software. It will generate INB, INP, INL files and the INB (board) file is directly used in the software for analysis.

6 General Assumptions

- Total analysis is carried out assuming the board is operating under steady state condition.
- Since Beta soft does not allow board shapes with irregular contours, an equivalent contour has been developed by cutting the edges.
- The default component junction and casing temperature limits are considered as 125^{o}c & 100^{o}c.
- Thermal resistance across the interface of the board which is clamped to the chassis is constant and it is R=2^{0}C in/W.
- The heat transfer effect through the thermal vias is not simulated fully.

6.1 Environment Conditions

The board will be operating under the following ambient conditions:

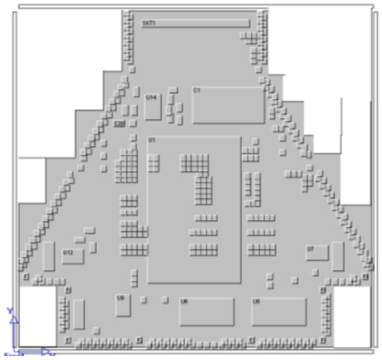
- Ambient temperature of 70 ^{o}C
- Board located in rack and Board is placed horizontally on aluminum chassis
- Total system is considered as closed System and the space between board top and casing wall is 14mm and 7mm between bottom side and casing wall adjacent casing wall emissivity is 0.8.
- Adjacent board power dissipation and incoming air velocities are 0 W and 0 mm/s

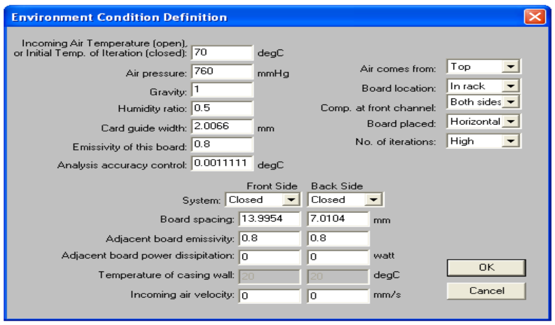
7.Results Of Thermal Analysis

7. 1 Simulation Settings for Thermal Analysis

<u>Iteration 1:</u>

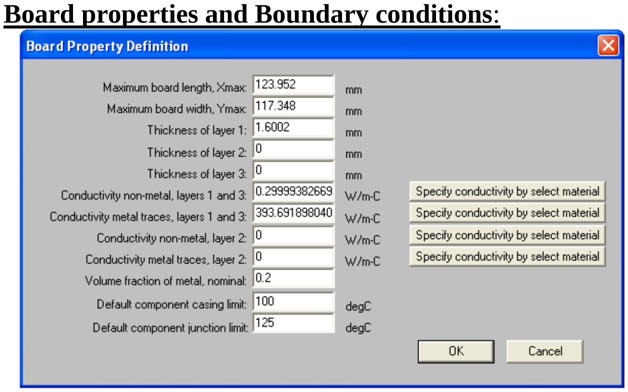
PCB thickness 1.6mm and without metal core Board model:

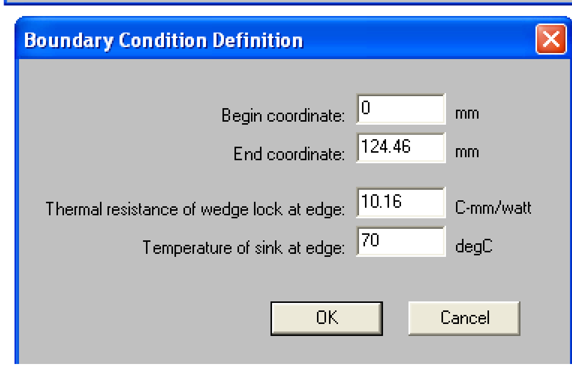




Environment conditions

Board properties and Boundary conditions:





Iteration 2:
PCB thickness 1.6mm with 0.1mm metal core Board properties:
The metal core thickness is taken as thickness of layer 2 and remaining thickness divided to layer 1 and layer 3

Iteration 3 :
PCB thickness 1.6mm with 0.2mm metal core Board properties:

Iteration 4 : PCB thickness 2.4mm without metal core Board properties:

Iteration 5 : PCB thickness 2.4mm with 0.1mm metal core Board properties:

Iteration 6 : PCB thickness 2.4mm with 0.2mm metal core Board properties:

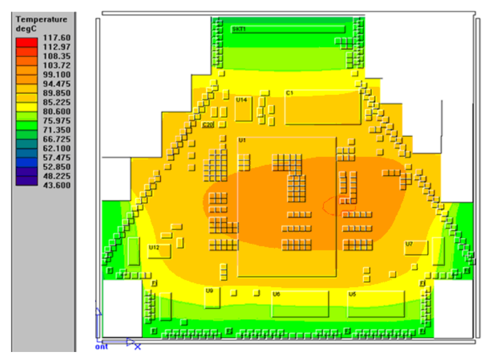
- Environment and boundary conditions are similar in all the iterations.
- Analysis has been carried out for all the above cases, the temperature distribution and excess temperature plots have been taken.

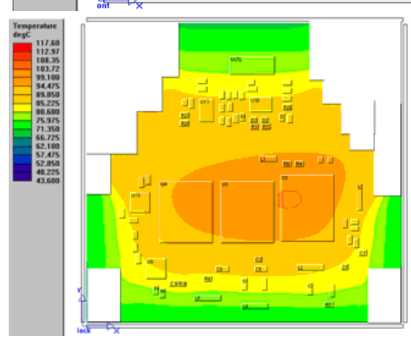
7.2 Results Of Thermal Analysis on Printed

Circuit Board: Following are the results of Thermal analysis on PCB:

- Temperature distribution analysis on the card
- Excess temperature analysis on the components
- Junction temperature and Case temperature analysis of components

Iteration 1: PCB Thickness 1.6 mm without Metal Core

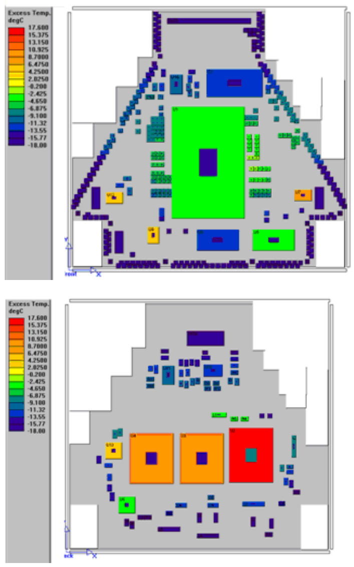




Temperature Distribution On Top Side and bottom side

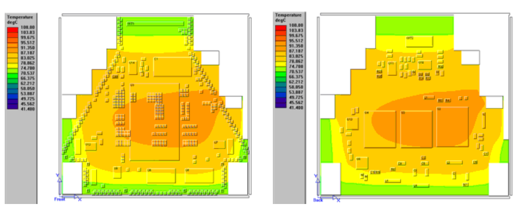
Iteration 1 :

PCB Thickness 1.6 mm without Metal Core



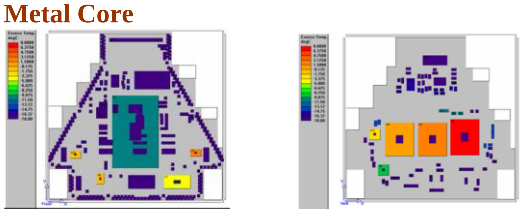
Excess Temperature On Top and bottom sides

Iteration 2 : PCB Thickness 1.6 mm with 0.1mm Metal Core



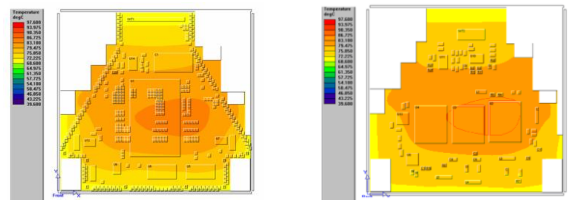
Temperature Distribution On Top and Bottom Side

Iteration 2 : PCB Thickness 1.6 mm with 0.1mm Metal Core



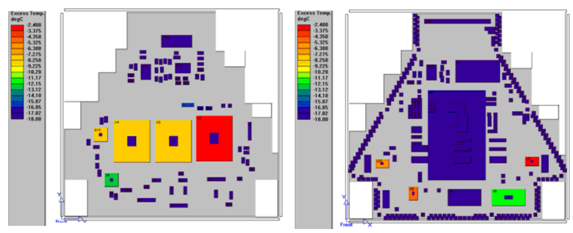
Excess Temperature On Top Side and bottom sides

Iteration 3 : PCB Thickness 1.6 mm with 0.2mm Metal Core



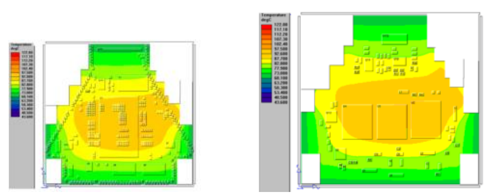
Temperature Distribution On Top Side and B0ttom Side

Iteration 3 : PCB Thickness 1.6 mm with 0.2mm Metal Core



Excess Temperature On Top Side and Bottom Side

Iteration 4 : PCB Thickness 2.4 mm without Metal Core



Temperature Distribution On Top Side and B0ttom Side

S.No:	Analysis Condition	Max temp. °C
1	1.6mm thickness PCB without metal core	117.6
2	1.6mm thickness PCB with 0.1mm metal core	108.0
3	1.6mm thickness PCB with 0.2mm metal core	97.6
4	2.4mm thickness PCB without metal core	122.0
5	2.4mm thickness PCB with 0.1mm metal core	114.3
6	2.4mm thickness PCB with 0.2mm metal core	103.8

Table2. (Hot Spot max temp)

CONCLUSIONS : The following are the thermal analysis results i.e. maximum temperatures and excess temperatures on the Prined Circuit Board (PCB) of Avionic Equipment with different PCB thickness and metal core thickness. The above results show the maximum temperature on the board for various analysis conditions. The maximum operating temperature up to which the components will perform without any deviation in their performance will be around 100°C.The excess temperature will indicate how much each casing and junction temperature of the components has exceeded their respective operating limits.The maximum temperature on the board with 1.6mm PCB thickness and 2 layers of Cu (0.2mm thickness) is 97.6°C. In this case the junction and casing temperatures of the components are well below their limiting temperatures. With 2.4mm thickness even though the values are very nearer, weight of the board will increase. Hence it is recommended to use metal core PCB of 1.6mm thickness with 2(1/2Oz) Cu la**yers.**

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NUMERICAL RESULTS:

Table 1 Analysis Component Details

7.3

Sl. No	PART DESIG.	PART No.	Qty	P (mW)	SIZE L x B x H (mmXmmXmm)	Tj (°C)	Tc (°C)
1.	U1	M-F1AM 7411	1	1000	58*56*13.7	140	125
2.	U2	MP028E036M12AL	1	5500	32*22*6.6	140	125
3.	U3	MP036F120M020	1	4400	32*22*6.6	130	110
4.	U4	MP036F120M010	1	3200	32*22*6.6	130	110
5.	U5	PTN0405AAH	1	1400	22*13*12	110	100
6.	U6	PTN0405CAH	1	500	22*13*12	110	100
7.	U7	ASSR-1611-001E	1	880	7.8*6.6*4.7	125	100
8.	U8	ASSR-1611-001E	1	880	7.8*6.6*4.7	125	100
9.	U9	ASSR-1611-001E	1	880	7.8*6.6*4.7	125	100
10.	U10	ACSL6400	1	100	10*6.2*1.3	175	150
11.	U11	ACSL6400	1	100	10*6.2*1.3	175	150
12.	U13	5404, 5408	1	250	9*9*2	175	150
13.	U13	5404, 5408	1	250	9*9*2	175	150
14.	U14	ACSL6400	1	100	10*6.2*1.3	175	150
All other components (capacitors and resistors) are not mentioned in the table 4.1 They are not contributing to major power dissipation but they are considered during analysis.							
Total board power dissipation = 20W							