A STUDY ON CURRENT CARRYING CAPACITY OF SINGLE LAYER PCB

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2nd JULY 2012

I hereby declare that I have read through this report entitle “A Study On Current Carrying Capacity Of Single Layer PCB” and found that has comply the partial fulfilment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power).

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Date : ………………………..

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A report submitted in partial fulfillment of the requirements for the degree of Electrical Engineering (Industrial Power)

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JUN 2012

I declare that this report entitle "*A Study on Current Carrying Capacity of Single Layer PCB*" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : MUHAMMAD A'ZIM HAKIM B. SHAHARBUDIN

Date : 2 JULY 2012

To my beloved mother and father

ACKNOWLEDGEMENT

I would like to take this opportunity to express my gratitude to all the parties that have been assisting me throughout the duration of my final year project report.

First and foremost, I would like to shower a million thanks to my supervisor, Miss Arfah Binti Ahmad who has been of outmost help and patience. From the first I was started my final year project, until the end, she has been my source of motivation, inspiration, and my guiding light. All the input toward the meeting with her has tremendously benefited me in various aspects and kept in a corner of my mind at all times while developing this project successfully.

Last but not least I would like to thank all my family members and friends who have been extremely supportive throughout the duration of the entire project and helping me to complete my final year project report.

ABSTRACT

Realizing the increasing importance and demand of a single layer Printed Circuit Board (PCB) in high current carrying capacity is subject of a closer research. This report address on correlations between electrical current and temperature rise on PCB traces. A temperature rise or thermal management is one on of the most important consideration on PCB design that can brings damage to the board if the PCB traces is exposed to a higher temperature than its limits. To prevent this problem, the period of erosion of copper track of the PCB will be estimated from a series of analysis of temperature rise in a single layer PCB. The relation between current and temperature rise in the copper trace of single layer PCB with different width and condition of the trace will be determine. The aim of this research is to determine a relation between current and temperature rise under performance on PCB board. The method to perform this experiment is using current injection from electrical device into PCB trace and the heat will be captured by using a FLIR thermal imager. Finally, data obtained will be analyzed by using statistical approach.

ABSTRAK

Projek ini berkaitan dengan mengkaji keupayaan pengaliran arus (CCC) bagi dua lapisan papan litar bercetak (PCB) dengan menggunakan pendekatan statistik. Sejak beberapa tahun kebelakangan ini, reka bentuk PCB seperti komputer riba telah menjadi semakin padat dengan pengecilan saiz dan kepadatan elektronik. Oleh itu, ia adalah penting untuk merekabentuk pengalir PCB bagi tujuan tersebut. Tujuan projek ini adalah untuk menentukan faktor-faktor yang mempengaruhi keupayaan pengaliran arus dan kelesapan haba serta hubungan antara pembolehubah-pembolehubah ini. Projek ini tertumpu kepada dua lapisan PCB, arus masukan pada pengalir, kelebaran pengalir, dan sudut pengalir. Faktor-faktor yang tetap pula adalah panjang pengalir dan suhu bilik. Untuk reka bentuk PCB pula, perisian PCB Express digunakan untuk memudahkan dan menjimatkan masa untuk proses mereka-bentuk kelebaran dan sudut pengalir yang diingini dalam kajian ini. Selepas reka bentuk PCB telah dibuat, PCB tersebut akan menjalani proses goresan untuk membuang pengalir-pengalir lebihan yang tidak digunakan atas papan. Ketika eksperimen, arus akan dialirkan ke pengalir pada PCB. Selepas 10 minit, suhu pada pengalir pada PCB akan stabil dan data akan diambil menggunakan FLIR Thermal Imager. Untuk memastikan yang data adalah tepat, data perlulah diambil sebayak 5 kali untuk setiap pengalir pada PCB. Kenaikan suhu pengalir pada PCB adalah disebabkan oleh beberapa parameter dan beberapa parameter juga tidak memberi kesan kepada kenaikan suhu pengalir. Ia menghuraikan tentang hubung kait diantara arus elektrik dan kenaikan suhu pengalir. Apabila terdapat kenaikan suhu disebabkan pengagihan dan kelesapan haba semasa aliran arus yang melalui pengalir PCB, ini boleh menyebabkan PCB gagal untuk beroperasi seperti biasa dan mengakibatkan kemusnahan bagi operasi PCB.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background

In recent years, the design of Printed Circuit Board (PCB) current carrying capacity such as personal computer (PC) has become increasingly dense with miniaturization of electronic packaging. At the same time, the speed of a digital electronic device used increase make more electrical current must be delivered to the device, typically via a PCB. This imposes certain limitation and critical requirement. Multi-media portable device such as hand phone and tablet phone which comes with less weight and smaller size is increasing the demand and provides an extra problem for PCB design.

Thermal management is one of the most important considerations in PCB design. The heat is distributed and dissipated during current flow which may potentially result in PCB fail to operate normally. This situation requires scheduled preventive maintenance activities as well as high operation cost. By predicting the temperature rise on the current carrying capacity of PCB, a failure on the PCB or malfunction of an electronic device can be minimized.

Prediction of the temperature rise on the PCB involves an experiment and calculations. Constructing the prototype PCB and performing an experiment with the prototype board in a laboratory is the best and most accurate method, but result in time consuming and money costly. However, to obtained data sometimes it is restricted for certain design of PCB and required a repeated experiment with different PCB design. Thus, other design alternatives which also inexpensive and less time consuming should be employed.

One of the alternative methods is by using statistical approach such as data analysis technique. This technique generally requires complete parameters to obtain a perfect solution. For problem of temperature rise on PCB which involving a complex geometries, loading and material properties, it is generally not possible to obtain a solution using this method. Beside, this method is valid for infinite number of location on the PCB. Hence, it is required to employ alternate method which is data analysis technique such as linear regression analysis.

1.2 Problem Statement

According to Institute for Interconnecting and Packaging Electronic Circuits (IPC) standard, the current carrying capacity of PCB traces represent the maximum electrical current that can be carried continuously by a trace without causing an objectionable degradation of electrical or mechanical properties of the devices. When current flowing through the copper trace and the current will generates heat in the copper will causes a deposition of thermal energy in that copper. The heat then will create a temperature rise between the trace and the surrounding environment (others microelectronic components). Hence, if the trace is exposed to a higher temperature than its limitation, the PCB could damage or worst case the PCB will explode and the electronic device will be caught on fire. This happen because the heat from the copper traces is not dissipated properly from the copper traces itself.

However, the relationship between current and temperature rise in PCB just not depend on the trace copper. There are a lot more variable that may have a significant impact on the PCB current carrying capacity. Some of those variables are PCB size and thickness, number of traces that are involved in current carrying, trace separation, presence or absence of the ground and/or power copper lane and system cooling condition. Only a few variables will be studying the relationship between current and temperature rise such as single layer PCB, copper width and straight or bended corner line. This parameter is one of the problems for the industrial because PCB is widely used in all electrical devices with high current carrying capacity flow through the PCB board. As the problem keep remains exist there should be solutions on how to determine the best temperature for PCB board.

1.3 Project objective

There are three objectives that need to be achieved to complete this project which are

1) To study current distribution and heat dissipation of current carrying capacity.
2) To build a PCB board for data collection.
3) To develop statistical equation for modelling ideal temperature on PCB.

1.4 Project scope

This study focuses only on a single layer PCB. The base material of the board is FR4 Glass-Epoxy Single Sided. The size of the board is 150mm (width) x 300mm (length). The trace spacing of the copper is not fixed with the other copper traces. According to the journal by Mike Jouppi's on his journal regarding current carrying capacity. Literally, there are two types of parameters that are identified to get the relationship between current and temperature rise.

The parameters are copper trace and trace condition which straight line or bended corner. The copper width that has been investigating is 0.06 inch, 0.08 inch and 0.10 inch. As the bended corner is about 110°, 130° and 150°. The current ranging from 0-5 Ampere was injected to each trace line and bended copper. Thus, the selected injected current has been decided is 1A, 3A and 5A to get a better result and easy to analysis the data. The data which had obtained from the experiment was analyzed using statistical software which is Minitab.

CHAPTER 2

LITERATURE REVIEW

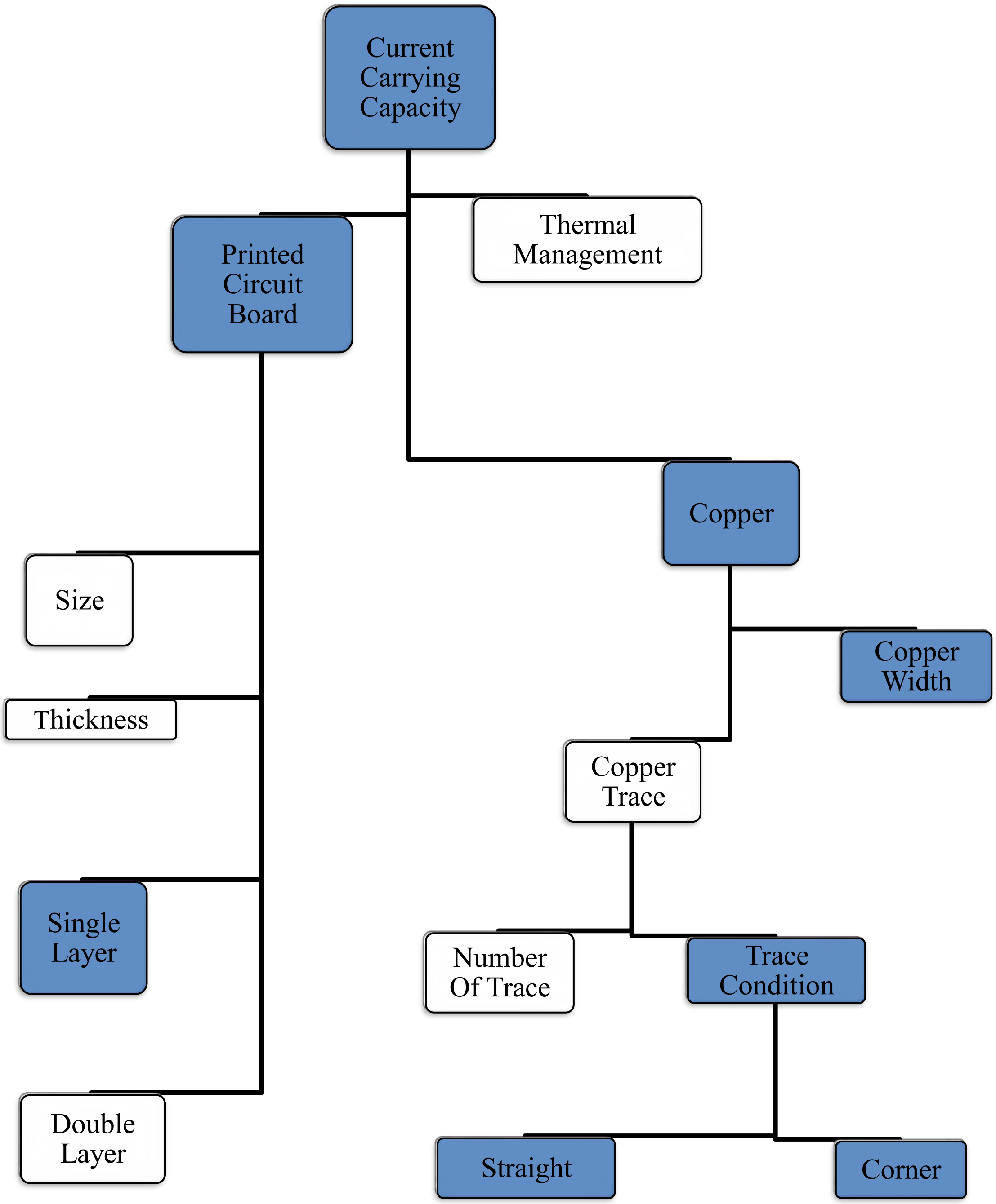

Figure 2.1 K-Chart Map

2.1 Introduction

This chapter highlight the past studies related to this project and background theory.

2.2 Current Carrying Capacity

Thermal management is an important design consideration in modern electronic packaging according to a journal written by Tsung-Yu Pan titled "*Current Carrying of Copper Conductors in printed Wiring Boards*" [1]. The author state that the requirement of the current carrying capacity of copper conductors on the surface of a printed wiring board due to temperature rise has not been studied thoroughly since the generic handbook data being published. In this journal, the author discuss more about the effect of thermal management of the copper conductors on Printed Wiring Board (PWB) or what they called now is Printed Circuit Board (PCB) having a different dimensions and arrangement. The author also stated that the experiment is used an infrared thermal as experiment basis. Then finite element analysis will be applied to correlate temperature rise versus conductor dimension and spacing, current amount and board dimensions.

Thermal resistance, *Rt*, has been widely used to described the thermal characteristic of electronic packaging. *Rt* is defined as:

$$Rt = \Delta T / Q \tag{2.1}$$

where ΔT = temperature increase in °C,

Q = heat flow rate in Watt,

Rt = thermal resistance in °C/Watt, which is a parameter analogous to electrical resistance.

To consider the heat management of copper conductor, a heat sink is not often considered because a copper conductor is usually having a big effect to PCB. So Rt is a combination of

i. Conduction through the board.
ii. Free air convection near the conductor and board surface
iii. Radiation into the surrounding component.

The heat flow, Q for the copper conductor is provided by an electrical current flow through the conductor. Q is proportional to current *I* and resistance *Re.*

$$Q = I^2\, Re \tag{2.2}$$

where I = current in ampere,

Re = electric resistance in Ω

$$Re = \rho\left(\frac{\ell}{tw}\right) \tag{2.3}$$

where P = electric resistivity in Ω-mm,

ℓ = length of the conductor in mm,

t = thickness of the conductor in mm,

w = width of the conductor in mm.

Therefore, $$\Delta T = Rt\, I^2\, Re \tag{2.4}$$

Figure 2.2 shows the temperature distribution on the PCB board surface across the conductor with current range of 1 to 3 ampere. It shows that thermal resistance *Rt* is not constant throughout the whole temperature range. This is because to the fact that *Rt* is a combination of conduction, free convection and radiation. Basically conduction through the board is always constant for different ambient temperature.

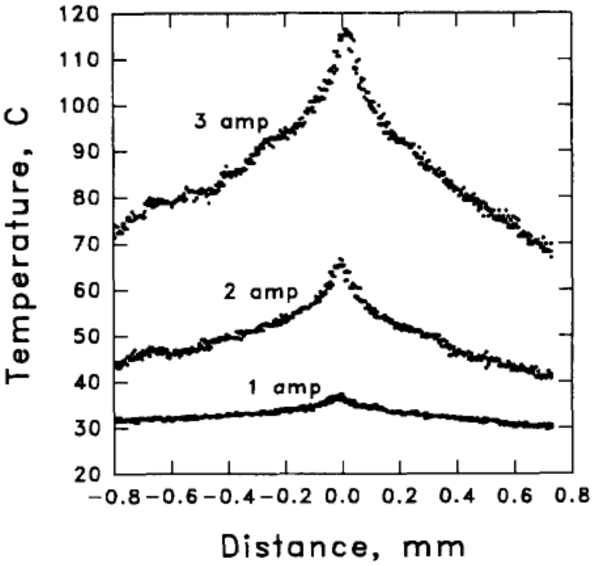

Figure 2.2 Infrared thermal imaging copper conductor

2.3 IPC (Interconnecting and Packaging Electronic Circuit) standard

The first standard chart that is often referred to is IPC 2152 performed by the National Bureau of Standards in 1956 [2]. According to the journal, this standard was established when printed circuit industry was in its infancy and when a guide for sizing conductor was first required. The original charts were developed from two different board materials, primarily XXXP (phenolic) and epoxy. These boards were 1/16 and 1/32 inch thick, had ½ oz, 1 oz, 2 oz and 3 oz copper conductor and some of the board had copper plane on one side of the board. The first parameters that been investigated by IPC are board material property, board thickness, copper weight and copper plane were influence trace temperature [2].

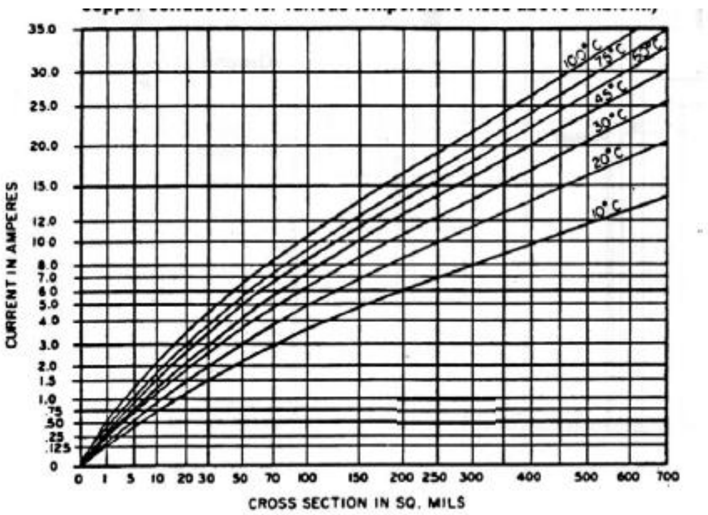

Figure A External Conductors

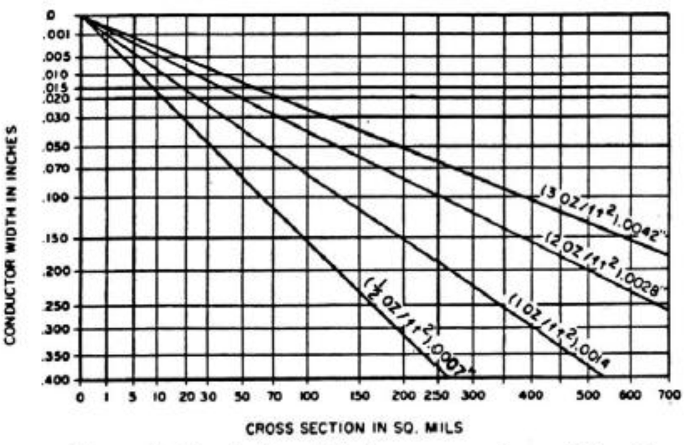

Figure B Conductor width to cross-section relationship

Figure 2.3 Conductor width to cross-section relationship

While working on a revision on IPC 2125, some of the journal has made criticisms about IPC 2125 regarding the design rule of PCB. The IPC Task Group 1-10b lead by Jouppi, believing the earlier version of IPC-2215 is inaccurate [3]. The close agreement between the experiment and the IPC correlation implies that the applicability of the IPC correlations is limited to PCB with little copper content. Nowadays PCB contains more copper, so that they can carry more current.

It also show that the 50% current de-rating of internal traces found in the IPC 2125 is not justified but must have been a matter of speculation at that time. Internal conductor heat and cool almost like external conductor. Another criticism is about cross sectional. Consider two traces of same cross-section, but different width *w* and thickness *t* as in figure 2.3.Let's assume the traces have the same current, the heat spreading topology and hence cooling system will be different.

By referring to figure 2.4 the heat flow into the PCB is primarily dominated by the footprint of the traces in example the width. The horizontal trace (left) will proved better cooling than the vertical trace (right) and will carry a higher thermal power or electrical current for the same temperature rise.

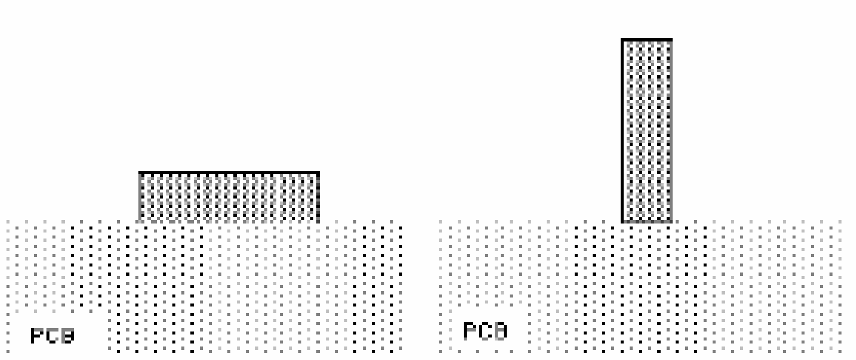

Figure 2.4 Flaw in IPC Standard

2.4 Characterization of FR4 PCB

Based on the literature review, there have been few attempted studies that were conducted on characterizing certain types of FR-4 laminates and assessing the impact of lead-free soldering assembly conditions on reliability of printed circuit boards. To date, no comprehensive report is available on the effect of lead-free soldering exposures on laminate material properties. Furthermore, a wide variety of laminate types that are commercialized as ‘Lead-free process compatible’ are available recently and selection of appropriate laminates has been a challenge for the electronic industry.

An insight into the laminate material constituents and variations in their material properties due to lead-free soldering exposures is essential in the selection of appropriate laminate materials. The broad objective is to characterize a wide range of commercially available FR-4 PCB laminate materials and investigate the effects of lead-free processing on the thermo mechanical, physical, and chemical properties. The analysis is aimed at correlating the properties to the material constituents of laminates [4].

Table 2.1: Some of the common PCB material types

Nomenclature	Reinforcement	Resin	Flame retardant
FR2	Cotton paper	Phenolic	Yes
FR-3	Cotton paper	Epoxy	Yes
FR-4	Woven glass	Epoxy	Yes
CEM-1	Cotton paper/woven glass	Epoxy	Yes
CEM-2	Cotton paper/woven glass	Epoxy	No
CEM-3	Woven glass/matte glass	Epoxy	Yes

2.5 Thermal Design Guideline

A thermal design guideline which is able to reliably predict the current carrying capacity (CCC) of PCB trace will be a valuable to PCB engineer. Thus, according to YI Wang [5] in her paper describes several design guidelines for the trace CCC. YI Wang also mention some of limitation to PCB design characterized dense component and high current applied to today's PCB. Hence, the new methods for developing a new design guidelines which are more efficient for today's PCB design has been introduced. As mention in the second review before, many experiment and research on PCB copper trace, thermal management has been done by referring to the IPC standard and IPC has come up with IPC-2125 which is expected to be more precise and comprehensive guideline in determining PCB design. The differences between YI Wang PCB design and IPC-2125 design, which is has a flaw on designing PCB are:

1) All guidelines are based on PCB with large area space. This can hardly be found in today's PCB
2) Single layer, multi-layers, trace corner, copper width is prevalent in PCB with more component density and high current density.

2.5.1 Discussion on new design guideline

All those guidelines gradually improved on the reliability and applicability of PCB design but none dwell on the fact that modern PCB has limited bare space. In practical, trace spacing (D) is much less than 30.5mm and sometimes less that 1mm [5].

1) To create a new standard for CCC on PCB board
2) To formulate a new PCB trace thermal design guideline which is applicable and reliable for high power density
3) The influence of single and multi layer
4) The corner effect on current carrying capacity
5) Methods for temperature measurement

Figure 2.5 show a different two set of PCB board with copper trace but with a different width and distance of copper trace. Figure 2.6 is exactly what is been done in this experiment which is a different width of copper trace such 0.06inch, 0.08inch and 0.10 inch but the distance between the copper trace is kept to be level of each other.

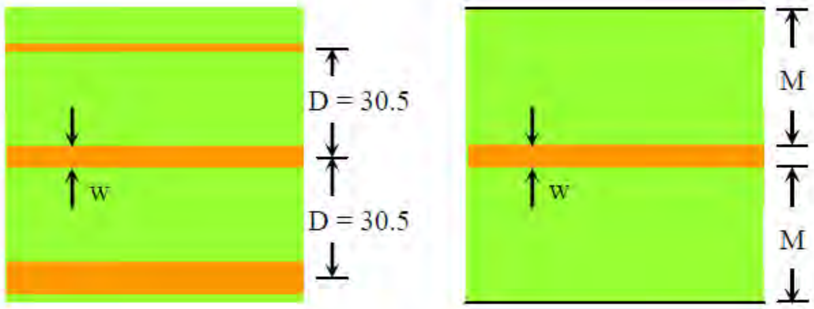

Figure 2.5

Figure 2.5: A Portion of board used in IPC-TM650

Table 2.2 is the result of investigating on the effect of trace spacing (D) with distance from edge (M) equals to 0 and 40mm. It is also show that M = 40 is appropriate to trace that are divided very widely and M = 0 appropriate to a dangerous case which the trace are hardly separated. As noticed that the trace has about 20 °C more temperature rise in case of M = 0.

Table 2.2:Measured Temperature of Trace on PCB with M=0 and M=40mm[5]

$w = 10$ mm, $I_{DC} = 20$ A	$M = 0$ mm	$M = 40$ mm
Measured Temp.	90.2 °C	69.3 °C

It is concluded that CCC results measured with large trace spacing M are too optimistic for the design. Large free space for heat dissipating can hardly be found in modern PCBs with higher component density[6].