IPC - 2152

[This is a working document. It is created for the purpose of review for major categories. The sections are being incorporated by the IPC Task Group 1-10b. Comments can be sent to mikej@thermalman.com]

Standard for Determining Current-Carrying Capacity In Printed Board Design

TABLE OF CONTENTS

Standard for Determining Current Carrying Capacity in Printed Board Design

May-03

Reference:

[1] NBS (National Bureau of Standards) Report #4283 "Characterization of Metal-insulator Laminates", D.S. Hoynes, May 1, 1956. Commissioned by Navy Bureau of Ships

1 Scope

This standard establishes the generic and specific guidelines for the design of metallic conductors in organic printed boards and other material that may be homogeneous, reinforced, or used in combination with inorganic materials.

1.1 Purpose

This document is intended as a guide to understanding the implications of applying current to any metallic conductor in a printed board design. The concepts can be applied to any metallic conductor printed on any media.

Interpretation -- "**Shall**," the imperative form of the verb, is used throughout this standard whenever a requirement is intended to express a provision that is mandatory. Deviation from a "shall" requirement may be considered if sufficient data is supplied to justify the exception.

The words "should" and "may" are used whenever it is necessary to express non-mandatory provisions. "Will" is used to express a declaration of purpose.

To assist the reader, the word "**shall**" is presented in bold characters.

1.2 Definition of Terms

The definition of all terms used herein shall be as specified in IPC-T-50.

1.3 Applicable documents

Institute for Interconnecting and Packaging Electronic Circuits (IPC)[1]

The following documents form a part of this document to the extent specified herein.

IPC - T - 50 Terms and Definitions for Interconnecting and Packaging Electronic Circuits

IPC - MF - 150 Metal Foil for Printed Wiring Applications

IPC - TM - 650 Test Methods Manual

IPC - 4102

IPC - 4104

IPC - ET-652 Guidelines and Requirements for Electrical Testing of Unpopulated Printed Boards

IPC - 2141 Controlled Impedance Circuits Boards and High Speed Logic Design

IPC - 4101 Laminate/Prepreg Materials Standard for Printed Boards

IPC - 2227

IPC - 4902

[1]The Institute for Interconnecting and Packaging Electronic Circuits

[6]IEEE

2 Conductor Design Overview

A process is presented for sizing electrical conductors that allows full flexibility to the application that is being designed. Sizing conductors is no longer limited to current, temperature rise and cross-sectional area. Charts similar to the existing current-carrying internal and external charts are a starting point for conductor sizing.

Optimizing the size of any conductor requires an understanding of the energy generated by the flow of electrical current through the metallic conductor and the resulting power dissipated by the conductor. Using that understanding along with computer aided thermal analysis software will allow the optimization of any design.

Designers **shall** understand what the design guideline represents. The process for evaluating design decisions is presented in Section 10, Design Process for Conductor Sizing. Using this process allows full design flexibility.

A conservative method of sizing conductors remains the same as previously with the exception of new charts. The new charts are based on test data that is described in Section 11, Test Data.

2.1 Earlier Concepts of Conductor Sizing and Current Carrying Capacity

Prior to the publication of this document, the minimum width and thickness of conductors on the finished board were determined on the basis of the conductor current required, and the maximum permissible conductor temperature rise. This method was derived from experimental results on external traces performed by the National Bureau of Standards in 1956, Reference 1. This document was established when the printed circuit industry was in its infancy and when a guide for sizing conductors was first required.

Appendix A contains the original charts that were developed for determining current-carrying capacity for external printed conductors for printed wiring boards. 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 conductors and some of the boards had copper planes on one side of the board. All of the boards were double–sided boards.

Board material property, board thickness, copper weight and copper planes all influence trace temperatures. Since all of these variables were lumped into a single chart the guidelines have produced mixed results. Designers have questioned the charts for years because of misunderstandings as to their origin.

2.2 Conductor Sizing Based on Cross-Sectional Relationship

Conductor sizing using cross-sectional area, applied current and temperature rise, as shown in Figure 3.1 is a generic case for sizing conductors. This method is applicable to the charts that have been added in Section 6.

(For use in determining current carrying capacity and sizes of etched copper conductors for various temperature rises above ambient.)

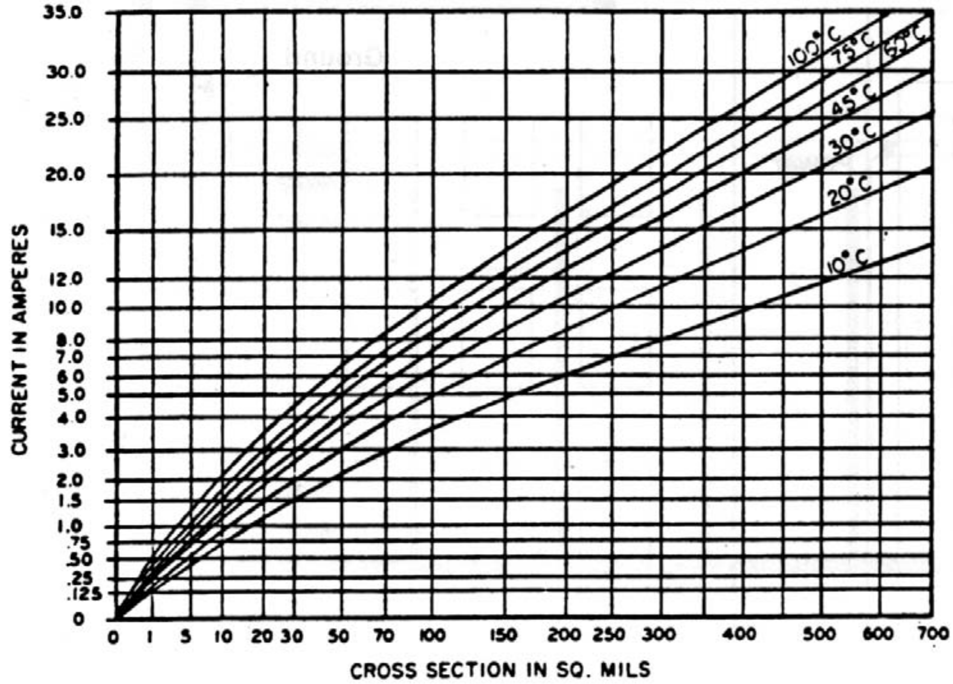


Figure A External Conductors

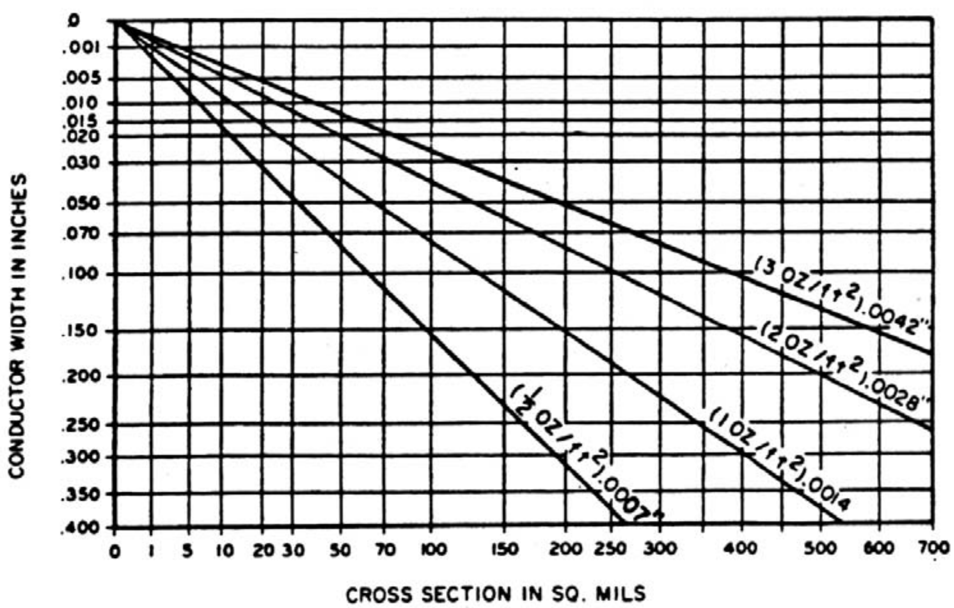


Figure B Conductor width to cross-section relationship

2.2.1.1.1

Figure 1 Conductor thickness and width for external layers

3 Thermal Management

The temperature of a conductor in a circuit board is dependent upon a number of variables. Some of these variables are the board material, thickness of the board, number of copper planes in the board, and the environment. The environment considers how the board is mounted and what it is mounted to, as well as if it is exposed to air, another gas or in Space (vacuum).

There is no simple way to define the temperature rise of a conductor. One method is to set a baseline for the temperature rise of a conductor and then optimize the conductor size based on the specific design. The optimization is highly dependent on the variables that determine the conductor's temperature rise. Aside from electrical performance, this optimization becomes a thermal management problem to be solved.

3.1 Basics of Heat Transfer

In the simplest of terms, the discipline of heat transfer is concerned with only two things: temperature, and the flow of heat. Temperature represents the amount of thermal energy available, whereas heat flow represents the movement of thermal energy from place to place.

On a microscopic scale, thermal energy is related to the kinetic energy of molecules, the greater a material's temperature the greater the thermal agitation of its constituent molecules. It is natural for regions containing greater molecular kinetic energy to pass this energy to regions with less kinetic energy. In other words, regions of high temperature transfer energy to regions of low temperature.

Several material properties serve to change the heat transferred between two regions at differing temperatures. Examples include thermal conductivities, specific heats, material densities, fluid velocities, fluid viscosities, surface emissivities, and more. Taken together, these properties serve to make the solution of many heat transfer problems an involved process.

3.1.1 Conduction

Conduction heat transfer occurs in any material whether solid, liquid or gas. This phenomenon is driven by a difference in the temperature within the material and is dependent on the material thermal conductivity. In electronics this value can range from 398 W/m-K for copper to 0.03 W/m-K for FR4 laminate material. The conductivity may not be constant in all directions particularly in a circuit board, where the copper layers play a critical part in the heat spreading.

3.1.2 Convection

Convection heat transfer is defined as energy transport by a moving fluid such as gas or liquid. The amount of heat transferred by convection from a solid to a fluid depends on the velocity and the temperature of the fluid. The convective flow is often described as being laminar (low velocity) or turbulent (high velocity). In turbulent flow there is a lot of mixing that occurs within the fluid and increases the amount of heat transfer.

Convection is a critical part in the design of electronic systems. It is often characterized as forced or natural convection.

Forced convection occurs when fans or pumps are used. Natural convection is characterized by a change in the fluid density with temperature.

There is no convection in space environments because there is no air or fluid that surrounds the electronics. With the exception of heat pipes and specially designed structures the only heat transfer that exists in space is conduction and radiation.

3.1.3 Radiation

Radiative heat transfer is defined as radiant energy emitted by a surface and is dependent on its temperature. Radiant energy is transferred between two surfaces proportionally to the difference of the fourth power of the surface temperatures.

All materials radiate thermal energy in amounts determined by their temperature, where the energy is carried by photons of light in the infrared and visible portions of the electromagnetic spectrum. When temperatures are uniform there is essentially no radiative flow of energy between the objects. Radiation heat transfer occurs from surfaces of higher to surfaces of lower temperature.

3.1.4 Heat transfer problem

An example will be discussed to pull the heat transfer concepts into perspective. A circuit board has an electrical conductor embedded into the board on layer six of a twelve-layer FR4 circuit board.

This is a conservative configuration, that represents trace testing, where there is only one trace in the board. The trace is six inches long, 0.254 mm [0.01 inches] wide and 0.0343 mm [0.00135 inch] thick (1-oz copper). The circuit board is 355.6 mm [14 inch] long, 203.2 mm [8 inch] tall and 1.57 mm [0.062 inch] thick. The trace runs horizontally across the center of the board and the board is suspended in still air. The air temperature is 25^{o}C and there is 1.12 amps applied to the trace.

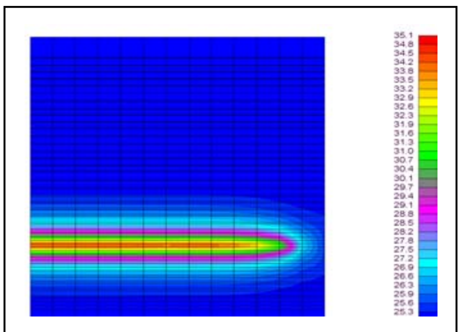
Under these conditions the trace peaks at 35.5^{0}C under steady state conditions.

The trace has a resistance of 0.328 Ohms. When 1.12 Amps flows through the trace there is 0.409 watts of power generated in the trace. This causes the trace to heat up. As the trace heats up the energy **conducts** away from the trace into the circuit board. The heat spreads out into the circuit board heating it up.

The board starts to heat the air around the hot spot on the board. As the air heats up (hot air rises) the air starts to move. As the air moves it starts to carry some of that energy (heat) away from the board. The energy is transferred to the air by **convection**.

The hot sections of the board radiate energy away from the board and transfer energy from the board to the surroundings.

Eventually, the amount of energy being transferred by conduction, convection and radiation reach equilibrium. Another word for equilibrium is steady state. In this case, the temperature of the trace stabilizes at



35.5^{0}C.

Figure 3.1 Heat Transfer Example

Although this may seem like an unrealistic case for a circuit board it is real for conductor heating. In fact, this is what the conductor charts represent. For further information in regard to what the charts represent read Section 9, Test Method.

3.2 Temperature Rise

When a temperature rise of a conductor is considered there are two conditions that can be discussed, steady state temperatures and transient temperatures.

3.2.1 Steady State

The conductor sizing design charts are only concerned with steady state temperatures. Steady state refers to a situation where the energy entering a system and leaving a system is in equilibrium. This condition is noticed when the temperature does not change under a given set of conditions.

The material property that is considered when determining the steady state temperature is the thermal conductivity of the material.

3.2.2 Transient (add fusing)

Thermal conductivity, specific heat and density for time dependent temperatures

Add mass issues

Work in fusing topic

3.2.3 Mounting Configurations

Sample of a card not mounted to anything

Sample of a card mounted to a chassis with wedge-locks

Sample of a card bolted to a heat sink

Sample of a card not mounted to anything with a convective environment with a velocity of X.

3.2.4 Altitude Effects

At increasing altitudes above sea level the density of air steadily decreases. As the density of air decreases the amount of energy transferred through convection to the surrounding air becomes less. At a high enough altitude the environment is considered a vacuum or Space environment with essentially no convection. At this time there are no charts to represent various altitudes, therefore at high altitudes it is recommended to review both Earth and Space charts.

3.3 Power Dissipation Considerations

Typically, the power dissipation from the electrical components on a circuit board is the concern that is addressed in a thermal analysis. There is power dissipated by the internal power planes in the circuit board and there is power dissipated by the circuit traces. It is recommended that consideration be given to the total power dissipated by all of the sources, (components, planes and traces) in a design.

3.3.1 Individual Component Power Dissipation

It is suggested to consider the conductor sizing in areas of high power dissipating components. The high power components are going to operate at high temperatures and therefore as a design consideration it may be helpful to lower the temperature rise of the traces in regions of high power components to minimize the local temperature rise in the board.

3.3.2 Board Material Properties

Thermal Properties

Thermal property discussion

Laminate properties

Resin

Fiber weave, content

Thermal conductivity

Table of Thermal Properties

Thermal conductivity

Specific heat

Density

4 General Circuit Features

A circuit board trace, depending on its size and the manufacturing process, is not necessarily rectangular in shape. For example Figure 4.1 shows a typical cross section of a trace.

Figure 4.1 Conductor Cross Section

The average thickness of a conductor is assumed to be as described in Table 4.1.

Table 4.1 Conductor Thickness

UL Numbers

Oz/ft$_2$	Inch	Microns
1/4 oz	0.00035	9
3/8 oz	0.00051	12
1/2 oz	0.0007	18
1	0.00135	35
2	0.00027	70
3	0.0041	105
4	0.0054	140
5	0.0068	175

6	0.0081	210
7	0.0095	245
8	0.0108	280
9	0.0122	315
10	0.0135	350

Even though these are average values a significant amount of variation is allowed for the copper thickness. The amount of variation is dependent upon whether the conductor is internal or external.

4.1.1 Conductor Width and Thickness

+ - 5-10% tolerance on trace width is acceptable.

The width and thickness of conductors on the finished printed board **shall** be determined on the basis of the signal characteristics, current carrying capacity required and the maximum allowable temperature rise. The charts in Section 7.3 are a baseline configuration. The designer **shall** understand what these charts represent. The designer should recognize that processing will vary the thickness of copper on circuit layers. See Tables 4.1.1-1 and 4.1.1-2.

The minimum finished conductor width used on the finished board **shall** not be less than 0.1 mm and, when the Underwriters Laboratories (UL) requirements are imposed, within the limits approved by UL for the printed board manufacturer (see UL746E). WE NEED TO PUT THE VALUES FROM UL 746E in here.

For ease of manufacturing and durability in usage, conductor width and spacing requirements should be maximized while maintaining the minimum desired spacing requirements. The minimum or nominal finished conductor width **shall** be shown on the master drawing.

Table 4.1.1-1 Internal Layer Foil Thicknesses After Processing

Copper Foil	**Minimum**	
1/8 oz	3.5 µm	0.000138 in
¼ oz	6.0 µm	0.000236 in
3/8 oz	8.0 µm	0.000315 in
½ oz	12.0 µm	0.000472 in
1 oz	25.0 µm	0.000984 in
2 oz	56.0 µm	0.002205 in
3 oz	91.0 µm	0.003583 in
4 oz	122.0 µm	0.004803 in
Above 4 oz	13 µm below minimum thickness listed for that foil thickness in IPC-MF-	

	150	

Table 4.1.1-2 External Layer Foil Thickness After Plating

Copper Foil	**Minimum**	
1/8 oz	20 µm	0.000787
¼ oz	20 µm	0.000787
3/8 oz	25 µm	0.000984
½ oz	33 µm	0.001299
1 oz	46 µm	0.001811
2 oz	76 µm	0.002992
3 oz	107 µm	0.004213
4 oz	137 µm	0.005394
Above 4 oz	For each succeeding ounce of copper foil, increase minimum conductor thickness by 30µm	

When bilateral tolerances are required on the conductor, the nominal finished conductor width and the tolerances shown in Table 2-3, which are typical for 46 µm copper, **shall** be shown on the master drawing for a typical conductor of that nominal width.

Table 4.1.2-3 Conductor Width Tolerances for 46 µm Copper

Feature	Level A	Level B	Level C
Without Plating	±0.06 mm	±0.04 mm	±0.015 mm
With Plating	±0.01 mm	±0.08 mm	±0.05 mm

If tolerances in Table 4.1.2-3 are too broad, tighter tolerances than Table 4.1.2-3 can be agreed to between the user and supplier and shall be stated on the master drawing and considered Level C. Table 4.1.2-3 values are bilateral tolerances for finished conductors.

The width of the conductor should be as uniform as possible over its length; however, it may be necessary because of design restraints to "neck down" a conductor to allow it to be routed between restricted areas, e.g., between two plated-through holes. The use of "necking down" such as that shown in Figure 4.1.2-1 can also be viewed as "beefing up." Single width, having a thin conductor throughout the board, as opposed to the thin/thick approach is less desirable from a manufacturing point of view as the larger width conductor is less rejectable due to edge defects rated as a percentage of the total width.

In any event, if the conductor width change is used, the basic design requirements defined herein **shall** not be violated at the necking down location.

When necking down a conductor it is recommended that the guidelines for conductor modeling be followed to evaluate the temperature rise in the reduced trace width.

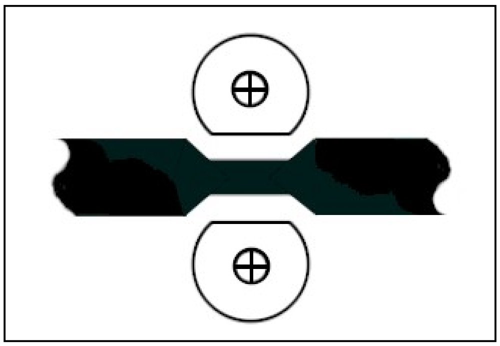


Figure 4.1.2-1 Example of Conductor Neck-down or Beef-up

5 Power Dissipation

When calculating a conductors power dissipation one is required to determine the resistance of the conductor and the current that is flowing through it. A circuit may have direct current (DC) or alternating current (AC). If the circuit is using AC a root mean square of the current, I_{rms}, must be determined. If the circuit is using DC the amperage can be used as it is.

The power dissipation is then determined by the following equation:

$P = I^2R$ DC circuit or in terms of voltage $P = VI$

$P = I_{rms}^2R$ AC circuit or in terms of voltage $P = V_{rms}I_{rms}$

5.1.1 Power Density

5.1.2 Electrical Resistance

The electrical resistance of a conductor would be expected to be greater for a longer conductor, less for a conductor of larger cross sectional area, and would be expected to depend upon the material out of which the conductor is made. Equations 5.1.2-1 and 5.1.3-1 relate the necessary terms for the calculation of resistance. The resistance can then be used to calculate the conductor power dissipation.

$R = \rho_v L/A$ Equation 5.1.2-1

Where:

ρ_v = 1.92 E-05 ohm-mm @ 25C for ½ oz. Copper

= 1.80 E-05 ohm-mm @ 25C for 1 oz. and over.

L= mm

R = Ohms

A = Area in mm^2.

5.1.3 Temperature dependence

$R = R_1[1+\alpha_1(t-t_1)]$ Equation 5.1.3-1

Where:

R = Resistance of conductor when adjusted for temperature.

R_1= Initial resistance of conductor at reference temperature (t_1).

t = Temperature of conductor that resistance (R) is being calculated.

$\alpha_1 = 1/(234.5 + t_1)$ = Temperature coefficient of resistance of the conductor at reference temperature (t_1).

t_1= Reference temperature; the ambient temperature at which R_1 is determined.

5.1.4 Volume Resistivity

The factor in the resistance, which takes into account the nature of the material, is the resistivity, ρ_v.

$R = \rho_v L/A$

Although it is temperature dependent, it can be used at a given temperature to calculate the resistance of a conductor of given geometry.

The inverse of electrical resistivity is called electrical conductivity.

$$\rho = 1.724 \times 10^{-8} \text{ ohm m}$$

Electrical conductivity = $\sigma = 1/\rho$

Resistivity at 20C		
Material	Ohm-mm	Temp Coef $^{o}C^{-1}$
Copper (pure) Copper ½ oz Copper 1 oz and greater	$1.68\ 10^{-5}$ $1.92\ 10^{-5}$ $1.80\ 10^{-5}$	0.00385 at 25°C
Silver	1.59×10^{-5}	0.0061
Aluminum	2.65×10^{-5}	0.00429
Tungsten	5.6×10^{-5}	0.0045
Platinum	10.6×10^{-5}	0.003927
Iron	9.71×10^{-5}	0.00651
The resistivity of copper at 20 C is about $\rho = 1.724 \times 1$	Reference: Giancoli, Douglas C., Physics, 4th Ed, Prentice Hall, (1995).	

5.1.5 Current

Electric current is the rate of charge flow past a given point in an electric circuit, measured in coulombs/second, which is named amperes.

5.1.5.1 Direct Current

In DC electric circuits the current in the circuit is related to voltage and resistance by Ohm's law.

Ohms Law $I = V/R$

I = current

V = voltage

R = resistance

5.1.5.2 Alternating Current

Circuit currents and voltages in AC circuits are generally stated as root-mean-square or rms values rather than by quoting the maximum values. The root-mean-square for a current is defined by

$$I_{rms} = \sqrt{\left(I^2\right)_{avg}}$$

That is, you take the square of the current and average it, then take the square root.

This is just the effective value needed in the expression for average power to put the AC power in the same form as the expression for DC power in a resistor.

As in the case with DC power, the instantaneous electric power in an AC circuit is given by $P = I^2R$, but the current is continuously varying. Almost always the desired power in an AC circuit is the average power, which is given by:

$P_{avg} = I^2_{rms}R$

Where:

I is understood to be the effective or RMS value of the current.

5.1.6 Transient Current Pulses

A transient (time dependent) condition is when current is applied for a time period less than steady state. Under these conditions the power dissipation must be calculated for multiple time steps over the period of the applied current. A multiple step process is recommended to solve the temperature rise for a transient current pulse.

Section 3.2.2 includes a discussion on modeling the transient temperature rise of a conductor.

5.1.7 Power Dissipation in Copper Planes

The power dissipation in a copper plane

is not a trivial problem to be solved. Many times the copper plane is of irregular shape and has multiple through-holes almost giving it a Swiss-cheese appearance. An approach to solving the temperature distribution in power planes is discussed in Section 7.5.1.

5.2 High Speed Design Considerations

There is no simple measure (such as RMS amplitude) that can possibly capture all the information that is needed to completely characterize the resistance, as the effective resistance depends greatly not only on the size of the AC fluctuations, but also on their frequency.

If you can establish an upper bound on the frequency content of your signals (such as is easily the case for most RF problems) and if you use that highest frequency for the calculation of skin effect depth then the conductor-sizing formulas should always be safe.

5.2.1 Skin Effect and Skin Depth

I have a section that I'm working on that will go in here.

6 Conductor Temperature Rise

There are many variables that affect the temperature rise of a conductor. Board thickness, board material, internal copper planes, mounting configuration, convective environment and whether the board is operated on Earth or in Space. Due to the complicated nature of determining the temperature rise of a conductor a basic configuration is used to describe a baseline temperature rise for a conductor. This baseline is determined by following the guidelines in IPC-TM-650, 2.5.4.1a, Reference 5.

It is important to acknowledge the variables that affect the temperature rise of the conductor. Understanding that there is more to the temperature response of the conductor than just current and cross-sectional area provides flexibility when designing circuit boards. Using thermal modeling techniques allows the design to be optimized by taking advantage of the positive aspects that these variables provide. Although without being able to take advantage of these techniques a designer must have safe design guidelines to layout a circuit board.

6.1 Influence of Board Thickness

The thickness of the board has some affect on the conductor temperature rise. Figure 6.1.1 shows results from both test data and thermal model simulations. The 1.78 mm (70 mil) thick PCB represents test data and the other thicknesses, 1.27 (50), 0.508 (20), and 0.254 mm (10 mil), are from steady state simulation results.

Figure 6.1.1 Board Thickness Effects

6.2 Influence of Board Material Property

The circuit board material property is a secondary effect on the temperature rise of the conductor. The exception to this case is when the thermal conductivity of the laminate material is significantly higher than standard laminate materials such as FR4 and polyamide. An additional exception is to when the conductor size is based on something other than test data, such as half the current from the external conductor data.

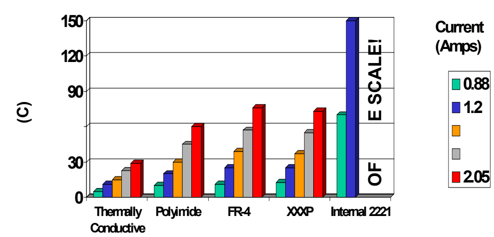


Figure 6.2.1 Board Material

6.3 Influence of Internal Copper Plane(s)

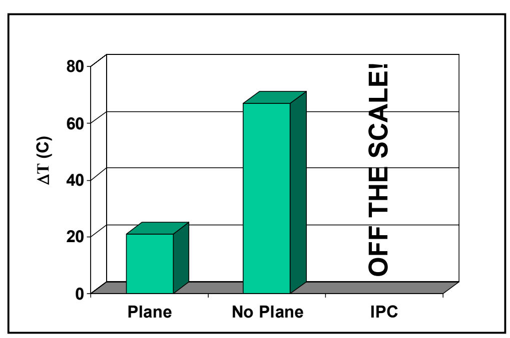


Figure 6.3.1 Internal Copper (Replace this one) remove IPC

6.4 Influence of Mounting Configurations

6.5 Influence of Convective Environments

6.6 Influence of Space Environments

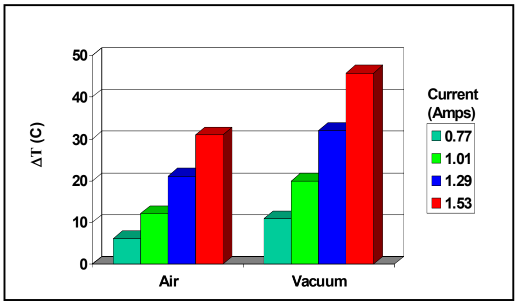


Figure 6.6.1 Air vs. Vacuum

6.7 Derating Factors

Derating factors are multiplication factors for reducing a value. For example, the charts are based on a board thickness of 0.07 inch. If the board thickness is 0.03 inch this affects the temperature rise of the conductor and a derating factor is provided to reduce the current.

7 Vias

The calculations used to size the cross-sectional area for current carrying capacity in vias and micro-vias is the same as for conductors. Typically, a via cross section is larger than the cross section of a trace entering or leaving it. The calculations for the cross sectional area is as follows:

8 Charts

The following charts are a subset of the charts that will be included over time. In the past, a single external and internal chart were used for sizing conductors. As mentioned in previous sections these charts are based on test data collected following the procedures in Reference 5.

Reference 5 provides a conservative method for determining the temperature rise of a conductor. Conservative in this case means that, in most cases, the conductor temperature rise will be less than defined by the use of these charts. Because these charts are provided as a general guideline they must set a baseline for conductor sizing. When the baseline is understood, then specific designs can take advantage of the variables that affect the temperature rise and optimize the conductor size.

Section 9, Test Data, discusses the test configuration and the data used to create the charts.

Charts will be included up to 30 oz copper weights. These will be added, as they are collected over time. Requests by industry will drive the priority and inclusion of new charts for heavier copper and lighter copper weights.

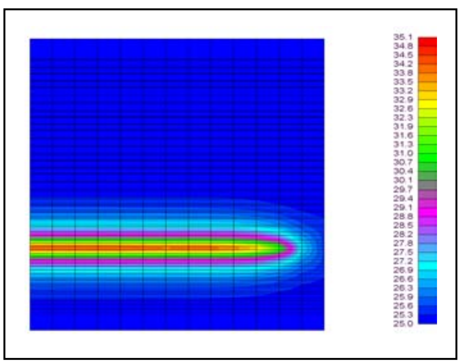
8.1 Parallel Conductors and Coils

The charts may also be used for the determination of temperature rise for other than single conductor applications, such as parallel conductors and coils. Tests on a limited number of samples show that the temperature rise of closely spaced parallel conductors may be estimated by using an equivalent cross section and current condition based on the summations of the cross sections and currents involved, and interpolating directly from the charts.

The following figures are presented to help illustrate the spacing that defines parallel conductors. The spacing is dependent upon the amount of heat spreading that occurs in a specific design. Each of the figures below represents a board configuration similar to that described in Reference 5.

Working on sections below

Figure 7.1.1 Single Conductor



The model in Figure 7.1.1 illustrates a metric units, 0.08 inch, conductor with current applied to it. Now, the rules for parallel conductors are illustrated. Two conductors of the same size as in Figure 7.1.1 are desired, so the current is added and the conductor is sized for the total current. That conductor is shown in Figure 7.1.2.

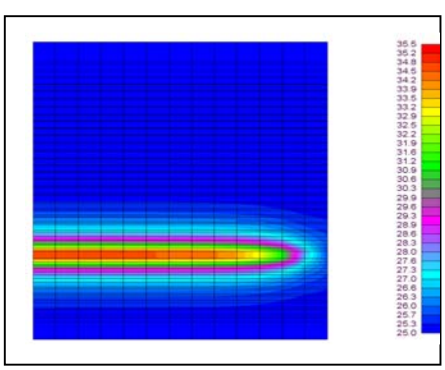


Figure 7.1.2 Single Conductor 0.160” metric

Figure 7.1.3 shows the two conductors with two of the same size conductors in parallel with metric, [0.07”], spacing. Conductor are separated to distances that exceed they temperature gradients that surround the heated conductor will the parallel rules.

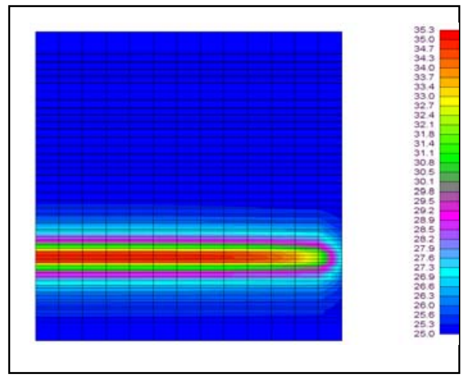
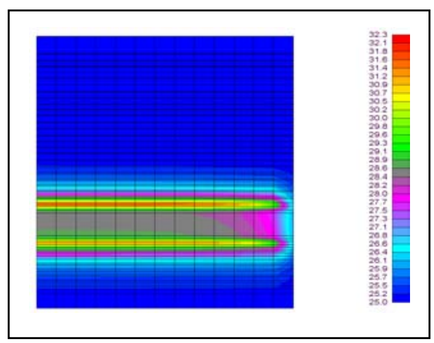


Figure 7.1.3 Parallel Conductors



Spacing

In the case of coils, estimates become somewhat more difficult owing to possible variations in conductor sizes, configurations, panel areas, and heat transfer from one part of the coil to another. Thermocouple measurements on a number of coils ranging in size from 0.350 inch to 1.5 inch diameter showed that safe estimates in temperature rise of the hottest portion may be made from the charts by utilization of equivalent cross sections an currents based on a factor of 2n, where n is equal to the number of turns in the coil. Here again, while the temperature rise estimates are generally on the high side, it is felt that little would be gained by introduction of correction factors of a complicated nature. This is considered particularly true in view of the inherent difficulties in obtaining accurate cross-sectional estimates from measurements due to variations in copper thickness, undercutting during etching, variations in the pattern, etc.

8.2 Table 1. Conductor Current Derating Values

Category (Internal Conductors)	Derating Value
Board Thickness 0.10” [mm] 0.08” [mm] 0.06” [mm] 0.05” [mm] 0.04” [mm] 0.03” [mm] Board Material	An equation for each material in addition to the derating factor.

8.3 Air/Earth Environments Charts

This section will be updated on a periodic basis depending on the demand for a given conductor thickness. The following is based on test data for polyamide test boards.

8.3.1 ½ oz Air

8.3.1.1 ½ oz fine line Air

8.3.2 1 oz Air

8.3.2.1 1 oz fine line Air

8.3.3 2 oz Air

8.3.3.1 2 oz fine line Air

8.3.4 3 oz Air

8.3.4.1 3 oz fine line Air

8.3.5 External 2 oz Air

8.3.5.1 External 2 oz fine line Air

8.3.6 External 3 oz Air

8.3.6.1 External 2 oz fine line Air

8.4 Vacuum/Space Environments

8.4.1 1/2 oz Internal VAC

8.4.1.1 1/2 oz fine line Internal VAC

8.4.2 1 oz Internal VAC

8.4.2.1 1 oz fine line Internal VAC

8.4.3 2 oz Internal VAC

8.4.3.1 2 oz fine line Internal VAC

8.4.4 3 oz Internal VAC

8.4.4.1 3 oz fine line Internal VAC

8.4.5 2 oz External VAC

8.4.5.1 2 oz fine line External VAC

8.4.6 3 oz External VAC

9 Thermal Modeling

Optimizing the size of conductors and achieving their desired temperature rise is difficult. There is no simple chart that can take into account the internal copper planes, board thickness, board material, mounting configuration and environmental conditions. An approach is presented

As electronics design optimization continues to be pursued for the sake of cost savings it is important to take into account all sources of energy that are present in a design. The conductors, embedded passives, power and ground planes are power sources in the board.

9.1.1 Power Planes

A computer aided modeling tool is recommended for solving the temperature rise in planes.

Prior to a model being solved with a computer aided analysis tool, all geometric elements must be converted into thermal resistances. There is a direct analogy between thermal resistance and electrical resistance. Because of this, some analysis tools can be used to calculate voltage drop as opposed to temperature drop. The following summarizes the correlations between thermal and voltage analysis.

Item	Is analogous to:
Temperature (Degrees)	Voltage (Volts)
Heat flux (Watts)	Current (Amps)
Resistance (Degrees/Watt)	Resistance (ohms or 1/Mohs)

9.1.1.1 Modeling geometry

There is a direct correlation for linear dimensions, so when a voltage-drop model is created, the actual dimensions for the problem are modeled.

9.1.1.2 Voltage sources

A voltage source in a PCB model is defined as a point where the user defines the voltage (temperature). This would typically be a power supply. This is analogous to defining a boundary temperature.

9.1.1.3 Current source (or sink)

A point in the model where a defined amount of current is added or removed can be represented as a heat load. If a component removes a specified current at a point in the PCB model, the current would be represented as a negative heat load at that point. If a voltage source acts as a constant current source as opposed to a constant voltage source, it would be represented as a positive heat load.

9.1.1.4 Electrical conductivity

For geometric elements, plates, bricks and tetrahedrons, thermal conductivity should be in units of Mohs/length where Mohs equals 1/Ohm. Units of length must be consistent with those used in the rest of the model.

9.1.2 Embedded Passives

Embedded passives represent capacitors and resistors that are embedded into the circuit board. Resistors are of primary concern as power dissipating components. The power dissipated by these components should not be ignored.

9.1.3 Conductor Sizing

The optimization of conductor

10 Test Data

All test data collected and used to create the charts in this document are based on following the test method described in IPC-TM-650. IPC-TM-650, 2.5.4.1, Conductor Temperature Rise Due to Current Changes in Conductors, has many of the same

An independent research group compiled data on ½ oz, 1 oz, 2 oz and 3 oz internal conductors. 2 oz and 3 oz external conductor data was collected.

11 Test Method

References:

[1] National Bureau of Standards Progress Report No. 4283, titled “Characterization of Metal-Insulator Laminates”, by D. S. Hoynes, dated May 1, 1956

[2] J. L. Sloan, Design and Packaging of Electronic Equipment, New York: Van Nostrand Reinhold Company Inc., 1985

[3] J. P. Holman, Heat Transfer, Forth Edition, New York: McGraw-Hill Book Company, 1976

[4] Frank Kreith, Principles of Heat Transfer, Third Edition New York: Intext Educational Publishers, 1976

[5] IPC-M-650, 2.5.4.1, Conductor Temperature Rise Due to Current Changes in Conductors.

[6] Harvard Thermal, Thermal Analysis Software, Thermal Analysis System (TAS) Help Documentation for Voltage Drop Analysis.