The Value of IPC-2152

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Abstract

Current carrying capacity in printed board design is technology dependent and an element of printed circuit board thermal management. Conductor temperature rise as a function of current is dependent on the number of copper plane layers in the board, how the board is mounted, the ambient environment (air or vacuum), board thickness, board material, conductor thickness, and conductor width. How does one go about creating a single standard for something that is so variable dependent?

IPC2152, Standard for Determining Current-Carrying Capacity in Printed Board Design, begins with a baseline configuration that provides a conservative method for sizing conductors for carrying current in printed circuits. New charts included in IPC-2152 are based on tests conducted on traces in boards with no copper planes, suspended in still air as well as in vacuum. The baseline represents a defined board thickness, board material, conductor width and thickness, as well as variations with respect to those variables.

IPC-2152 is a technology enabler. Through the use of computer modeling and information within IPC-2152 and the Appendix, current carrying capacity design guidelines can be optimized for any variation in printed circuit technology. Until the publication of IPC-2152 this was not possible with the available public information.

Discussion

IPC-2152 contains information that can be used to develop current carrying capacity guidelines for individual designs. Beginning with an explanation of the conductor sizing guidelines in IPC-2221, a discussion will be presented that illustrates the value in IPC-2152.

In 1955 the United States National Bureau of Standards was funded by the Department of the United States Navy to develop a method for evaluating conductor current carrying capacity in printed circuits. It was at a time when printed circuits were first being introduced as a technology. The conductor sizing design guidelines preceding IPC-2152 were based on the results of that funding. The end result was a chart labeled “Tentative”. Although it was published as a chart for sizing external conductors, it eventually became Mil-Std-275. That chart is shown in Figure 1.

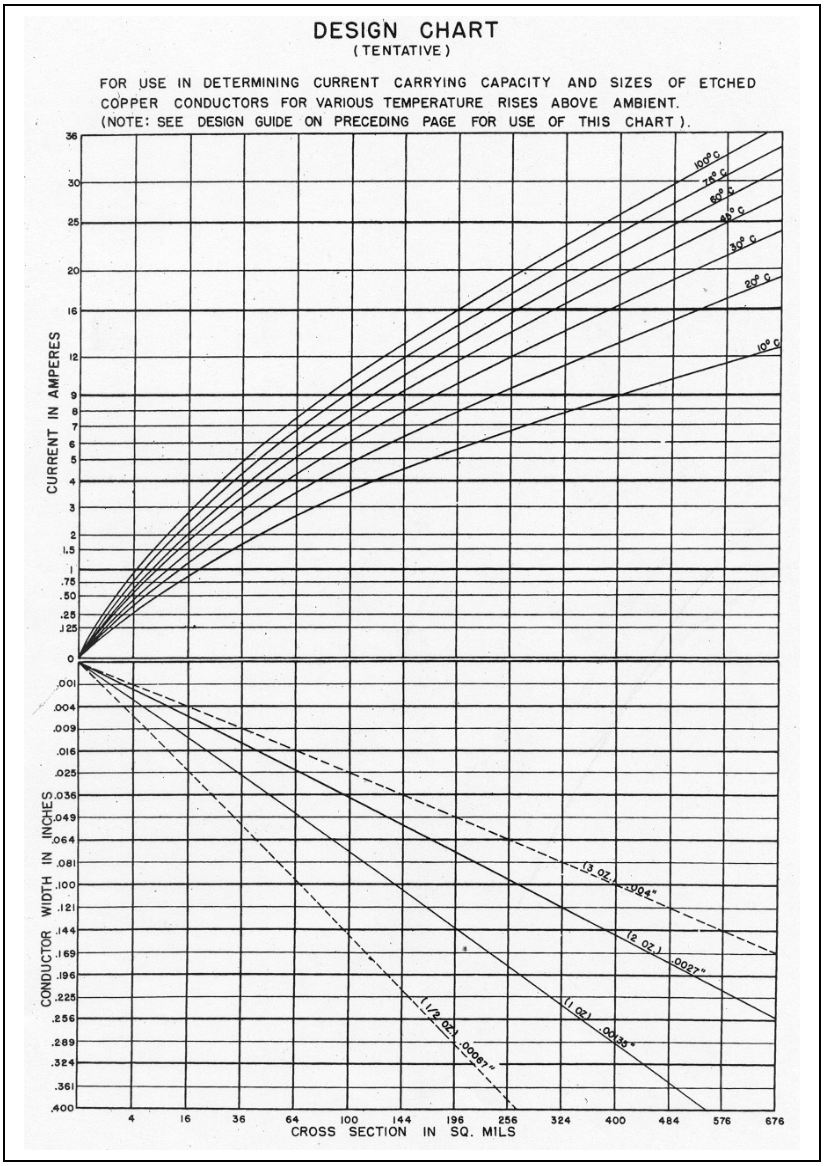


Figure 1 External Design Chart

The method used to size conductors, which will be addressed again at the end of this paper, is performed using graphs or charts. The graphs show a relationship between conductor cross-sectional area, applied current and temperature rise.

This method of sizing conductors is a heritage method that is well accepted, although misunderstood by many using the charts. Some of the confusion comes from trying to compare these charts with data collected from printed circuit assemblies or analytical results of the same. The internal conductor chart in IPC-2221 offers the biggest challenge when making these types of comparisons. The only way to understand the relationship between any given design and these charts is to understand the information used to create the chart being used. Figure 2 shows one set of results compiled for the purpose of developing the chart in Figure 1.

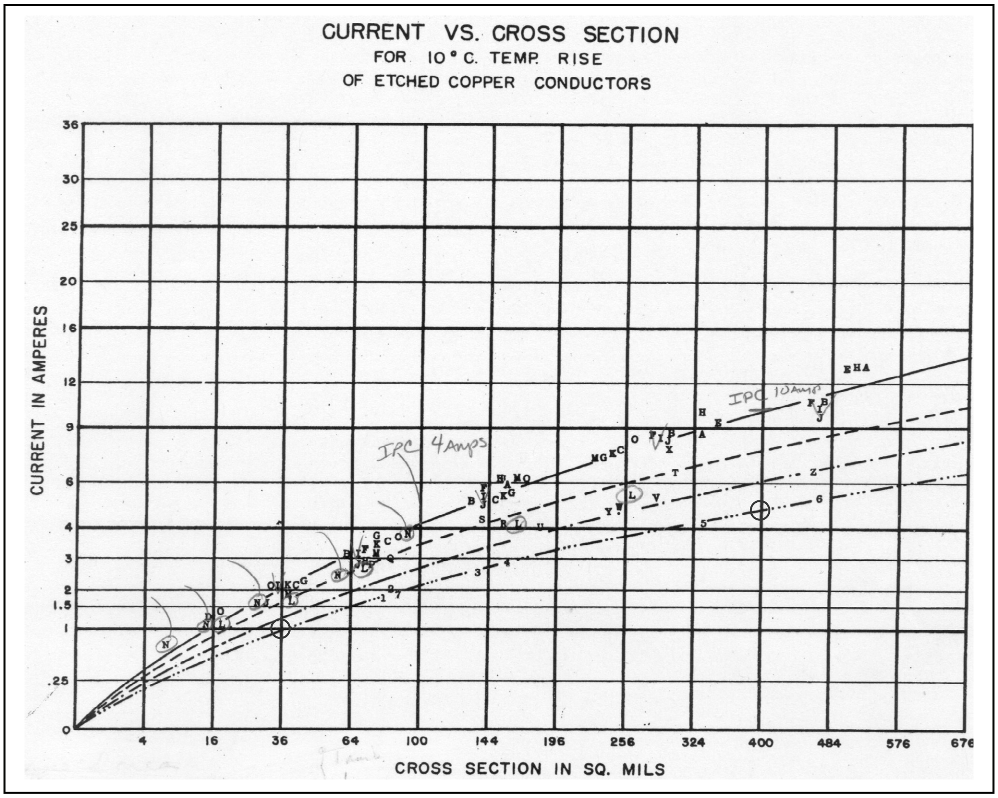


Figure 2. Original Data

Multiple test vehicles were used to develop Figure 2. Those test vehicles were used to collect conductor temperature rise data as a function of cross-sectional area vs. current from boards of multiple materials, varying board thickness, varying copper thickness, and boards that included copper planes, in multiple combinations. It also contains conductor temperature rise data from conductors stripped from the boards and tested in free-air. The lower line in Figure 2 represents the conductors tested in free-air, reference 1. Use points on this line, for example, 36-sq.mils and 1-amp in addition to 400-sq.mils and 5-amps, and compare this with the 10C line in Figure 3. In addition, compare the defined conductor size for 5 and 10-amps for a 10C and 45C temperature rise in figure 3 with figure 4. Then Figure 4 is a new chart for 1-oz conductors in an air environment from IPC-2152.

The IPC-2221 internal conductor sizing chart, Figure 3, actually represents a conductor in free air. This is not what one expects when initially making a comparison between actual data and thermal modeling results, although it offers insight into what can be used as a design criteria. This poses a question. Can there be a single chart that can be used to size conductors for all board designs? The answer is yes, although it is conservative and may not allow line and space sizing desired in a specific design. Figure 3 represents that chart. The next question is how different from Figure 3 is the current carrying capacity in a specific design?

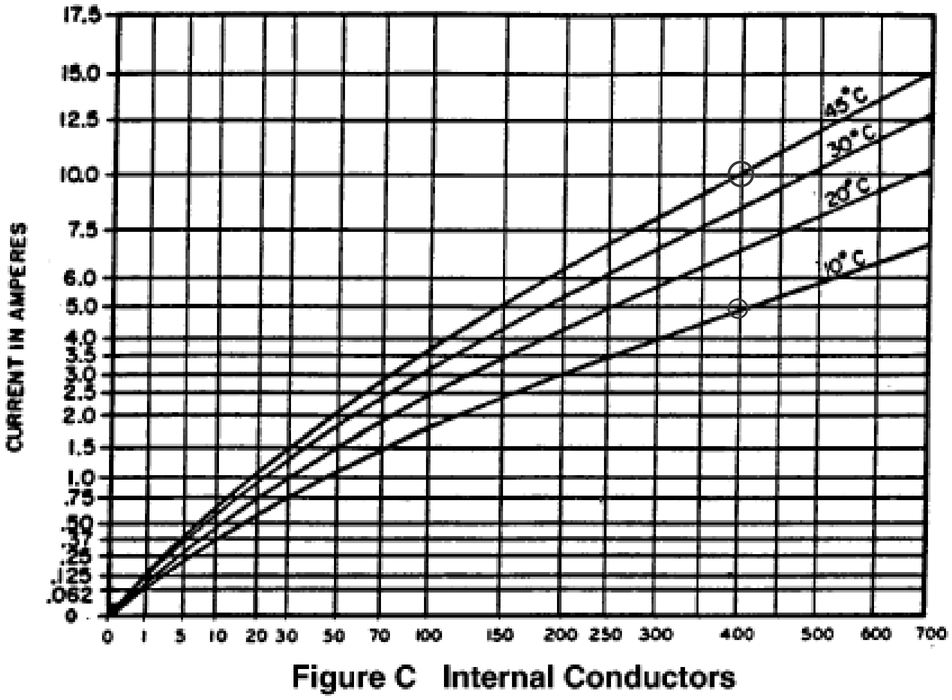


Figure 3. IPC-2221 Internal Conductor Sizing Chart

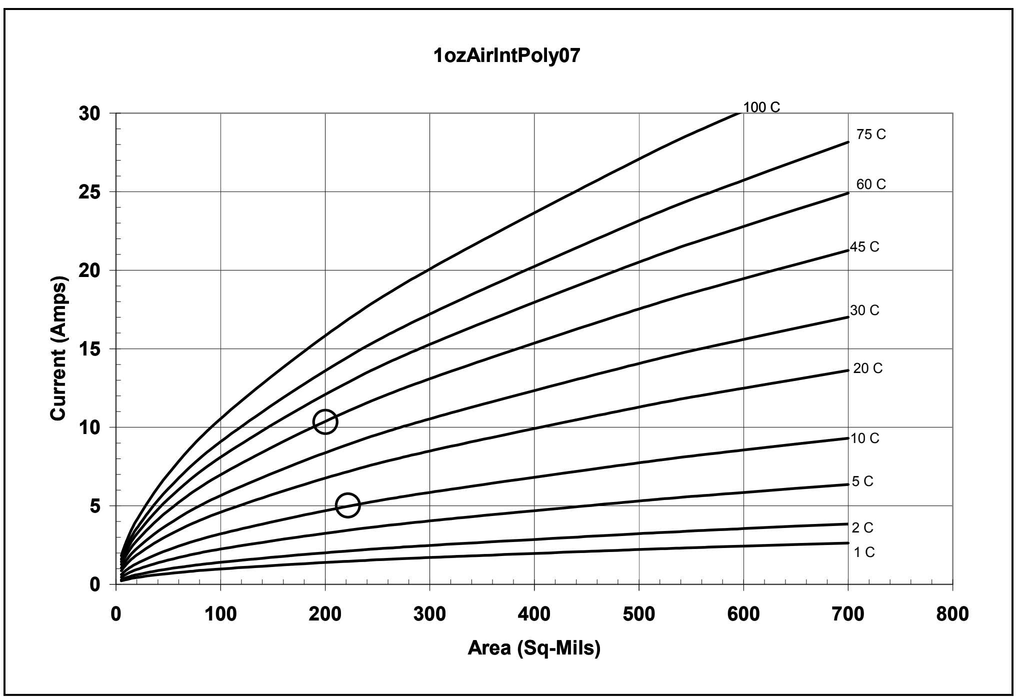


Figure 4. 1-oz Internal Conductor Sizing Chart

Fine Tuning Design Criteria

The old charts oversize conductors. The benefit from using them is that the impact to the thermal management of the rest of the printed circuit assembly is negligible. When optimizing trace size and spacing it is important to understand the limits of conductor temperature rise and current.

The use of charts allows conductor sizing without performing a thermal analysis on each new design. IPC-2152 provides new charts that are based on trace heating derived from testing in circuit boards. This offers a method for fine tuning charts into design specific guidelines for sizing conductors and provides a means of estimating design margins.

The method uses the linear aspects of heat transfer from the trace in a printed circuit board to manage the local conductor temperature rise in the board. Each of several variables can be used to identify a decrease or increase in the temperature rise of a conductor by multiplying by a factor that represents each variable when compared to the baseline. The variables are copper thickness, board thickness, board material, and copper planes. Another variable, which is suggested for users to investigate, is minimum allowable copper clad thicknesses and how it impacts cross-sectional area for small conductors.

Baseline

The baseline is a 0.07 inch thick polyimide test vehicle. The baseline test configuration is specified in reference 2. Temperature rise data as a function of current is developed from multiple traces, multiple copper weights, in air and vacuum environments for comparison. These variables, as well as copper planes and board material, are considered when fine tuning conductor current carrying capacity guidelines.

The influence on temperature rise from a specific variable can be made using the results presented in IPC-2152. For example, figure 4 shows the reduction in current necessary to achieve the same temperature rise when going from 1-oz copper to 2-oz copper and 1-oz copper to 3-oz at a specified cross-sectional area. Curves are shown for a 10C rise and 45C rise relative to a 1-oz conductor of defined cross-sectional area and applied current.

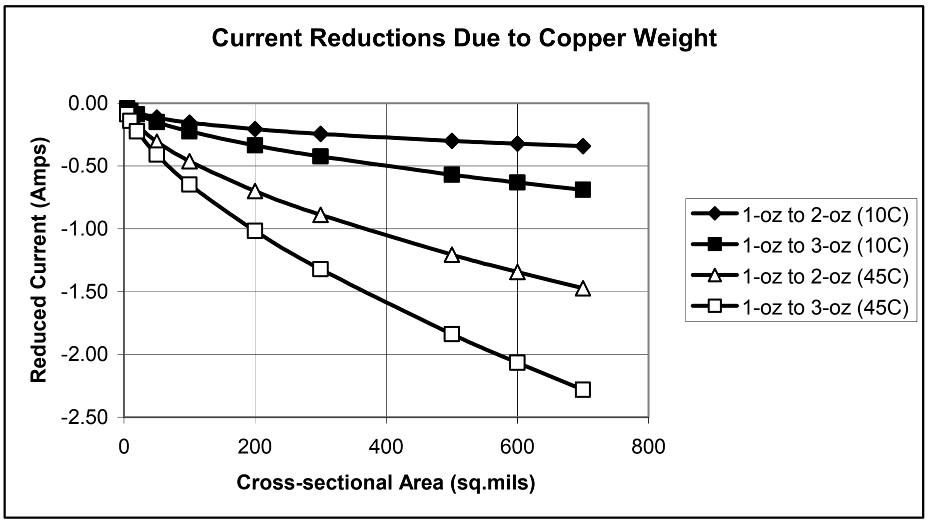


Figure 5. Current Reductions as a Function of Copper Weight

Board Material and Thickness

Data collected from test vehicles of different dielectric material (polyimide and FR4) and board thickness (0.059-inch and 0.038-inch) were used to compare against the baseline. In general, the small differences in thermal conductivity between the polyimide and FR4 test vehicles had little impact on conductor temperature rise. Although reducing the board thickness from the baseline increases conductor temperature rise. Test vehicle thermal properties were measured and are included in IPC-2152. Factors are included in IPC-2152 to take into account board thickness.

Each variable was evaluated one at a time in a design of experiments type matrix. The results are used to compare any one variable against the other. This allows conductor temperature rise estimates to be made for any design that differs from the IPC-2152 baseline. It also allows other parameters to be evaluated and used for comparison against the baseline, such as mounting configurations, forced convection, and transient currents.

Significant testing was performed for all board configurations except for boards with copper planes. A sample of copper plane data was collected and is used for comparison, although a full compliment of test data was not produced. Thermal analysis software tools were used to build models that were correlated to test data and then used to create charts for estimating the influence of copper plane layers on conductor temperature rise.

The presence of thermal (copper) planes for heat spreading have one of the most significant impacts on lowering conductor temperature rise. Caution is recommended when using the copper plane charts. Parallel conductor rules change when taking into account the reduction in trace temperature rise due to the presence of copper planes. Before going into an explanation of the use of copper planes a discussion on parallel conductors will be presented.

Parallel Conductors

Conductors that are side by side, as shown in figure 5, are most commonly thought of as parallel conductors. Many designers have neglected the layer to layer aspects of sizing parallel conductors that would result from designs similar to the traces illustrated in Figure 6.

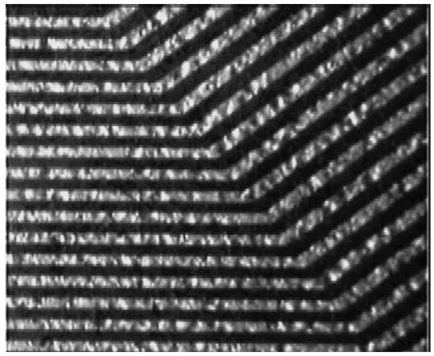


Figure 6. Parallel Conductors (Single Layer)

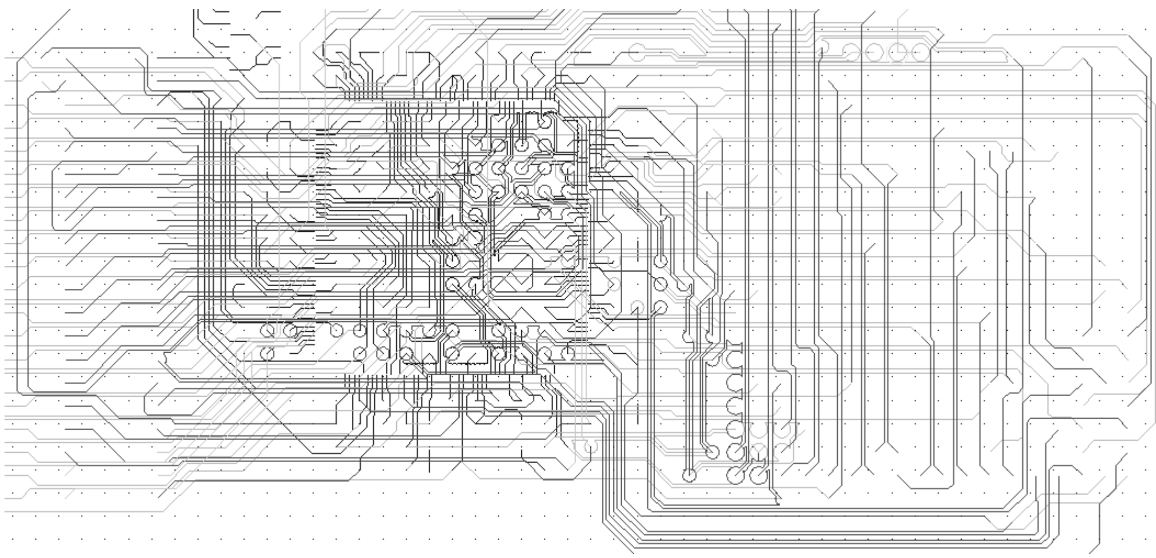


Figure 7. Parallel Conductors (Multiple Layers)

When sizing parallel conductors the temperature gradient between conductors is considered. Conservative guidelines are recommended in IPC-2152, which states that if conductors are within 1-inch of each other they are considered parallel. One inch is used because the influence from one conductor on another is small. An example is shown in figure 7. Figure 7 shows an increase in conductor temperature, for traces sized for a 10C rise, of only 2C higher than expected. If the two traces had spacing of a few thousandths of an inch the temperature rise of each trace would be 18C rather than the desired 10C rise. The impact on temperature rise is compounded by increasing the number of traces that are not properly sized following the parallel conductor sizing rules specified in IPC-2152.

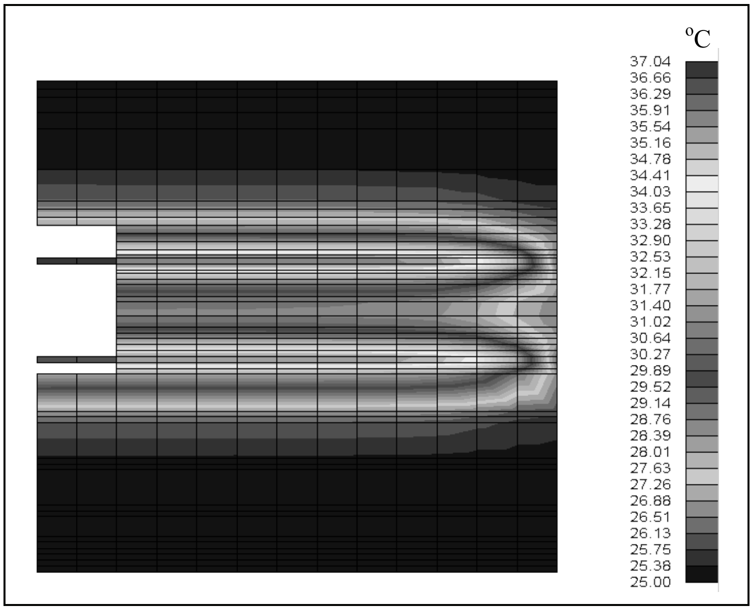


Figure 8. Parallel Conductors, Sized as Single Conductors

Increasing the spacing between traces reduces the influence on conductor temperature rise of one trace on the other. Figure 8 shows two parallel conductors, spaced 0.10 inch apart, each sized as single conductors. In this case the temperature rise is a little more than 17C rather than the desired 10C. Trace spacing must increase beyond an inch to not influence an adjacent trace. A compromise can be made by evaluating the gradient around the trace or using copper planes to evaluate margin in the design. The gradients around a trace are discussed in the parallel conductor section of the IPC-2152 Appendix. Figure 9 illustrates the temperature gradient around a single conductor sized to a 10C rise.

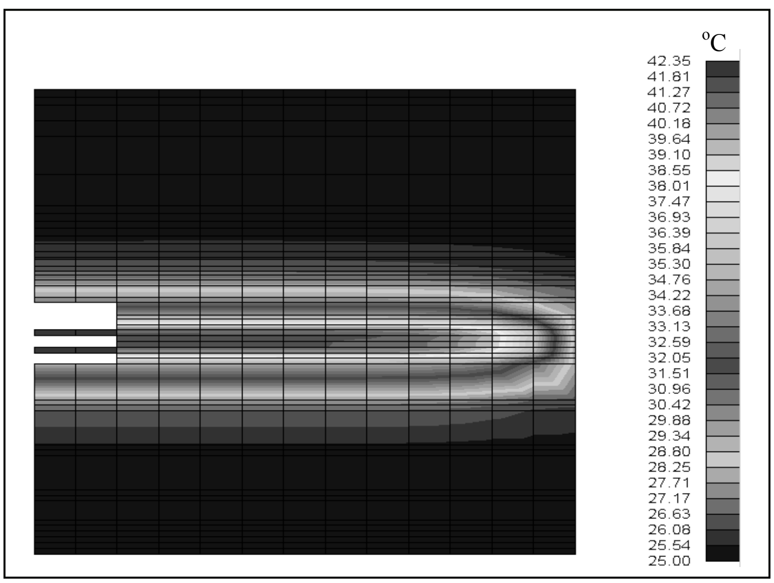


Figure 9. Two 0.080 inch Conductors, 0.10 inch spacing, Single Conductor Sizing

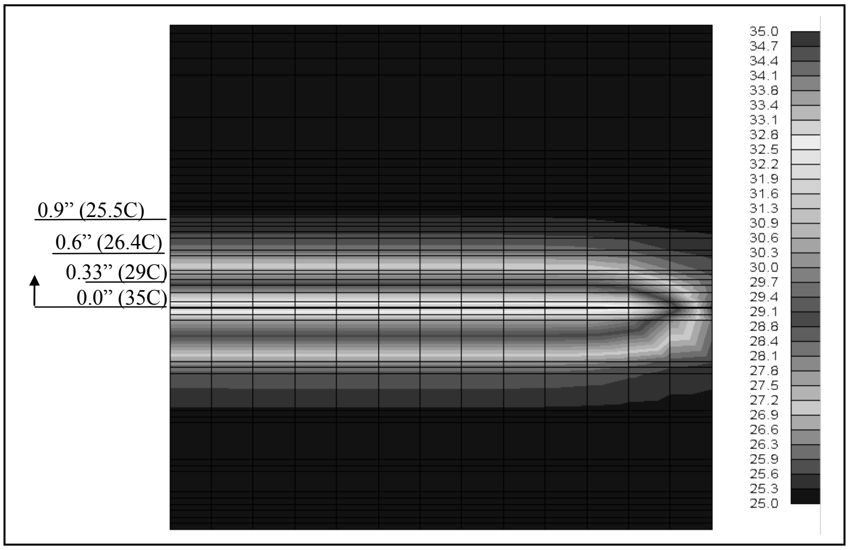


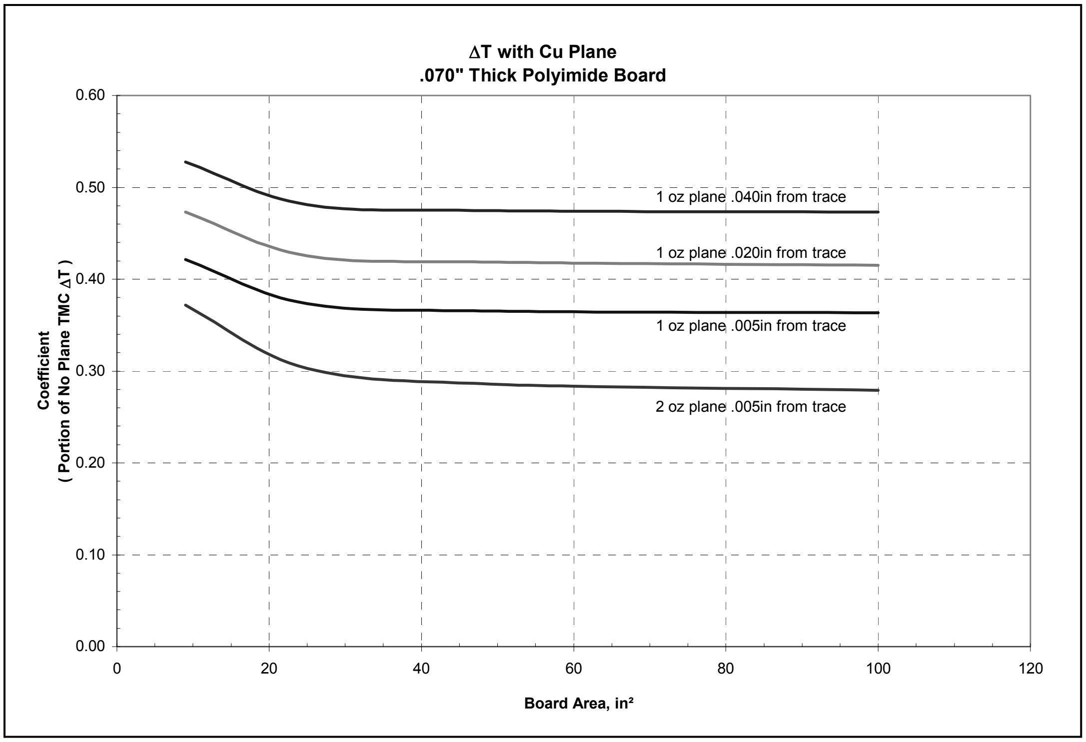
Figure 10. 0.010 in. wide (1-oz) Conductor (10 °C delta T) Temperature Gradient

Copper Planes

When copper planes are introduced into the process of sizing conductors, the rules regarding parallel conductors expands to include all conductors under or above the copper plane area. The reason is that the copper plane (or any thermal plane, aluminum, composite, etc.) will thermally couple the traces that are in the vicinity of the plane/planes. Therefore, when using the copper plane chart, all conductors under the area of the plane need to be considered as parallel conductors.

When conductor sizing rules are followed properly is when the copper plane chart is best put to use. The copper plane chart is a tool for determining design margin. Figure 11, the copper plane chart, is used with the baseline charts to calculate a reduction in the conductor temperature rise resulting from the presence of copper planes. The curves show the reduction in conductor temperature rise as a function of distance from trace to plane and size of the copper plane. It is assumed that the conductors are centered on the plane. The coefficient on the Y-axis of the chart is a multiplier that is used with a delta T calculated using the baseline chart in IPC-2152. For example, a conductor estimated to have a 30C rise calculated using the IPC-2152 charts will have a temperature rise closer to 9C when a 2-oz copper plane (5-in x 5-in [25sq.in]) is present in the design located 0.005-inch away from the trace.

Figure 11. Conductor Temperature and Copper Planes



Summary

The value of IPC-2152 is in the information that it contains. It answers questions that are asked on every Continent about why the internal chart that has been used since 1955 does not compare with engineering calculations and test data. It clears up miscommunications as to the origin of the charts that have been used for over six decades. It offers more information, regarding conductor temperature rise as a function of current and conductor cross-sectional area, than has ever been offered before. It also provides a way to expand on the available information through the use of the IPC-2152 Appendix.

This document not only answers questions but delivers a process of incorporating new findings such as the influence of mounting configurations, high current transients, flex circuitry, and expanding on the charts used for conductor current carrying capacity.

References

[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

[2] IPC-TM-650 2.5.4.1a, Conductor Temperature Rise Due to Current Change in Conductors, Dated August 1997.

The Value of IPC-2152

IPC-2152, Standard for Determining Current-Carrying Capacity in Printed Board Design

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The Value of IPC-2152

- How many people have worked on the development of a new standard?
- How many people have relied on volunteers and donations to develop a product?
- How many people have had thermal problems in their electronics designs?

The Value of IPC-2152

- Defining the bottlenecks in a process drives the desire to find solutions to those bottlenecks.
- Minimizing bottlenecks in any system ultimately results in optimizing the process.
- IPC-2152 helps manage the thermal impact of conductors on the pcb design.

Introduction

- Old conductor current carrying capacity guidelines
  - National Bureau of Standards 1955 data
- New guidelines
  - New data (conductor temperature rise and current)
  - Main document and Appendix
  - Conductor Heating
  - Variables that impact conductor temperature rise
  - Parallel conductors

Introduction

- How does IPC-2152 impact Printed Board thermal management?
  - Defines how to determine conductor temperature rise
  - Takes into account many of the variables that impact conductor temperature rise as a function of current
- IPC-2152 offers more <u>flexibility</u> and more information for design decisions than has ever before been offered.
- Current carrying capacity in printed board design is <u>technology dependent</u> and is a <u>thermal management issue</u>.

Old Guidelines

- Is it possible to have a single chart for conductor current carrying capacity? Yes!

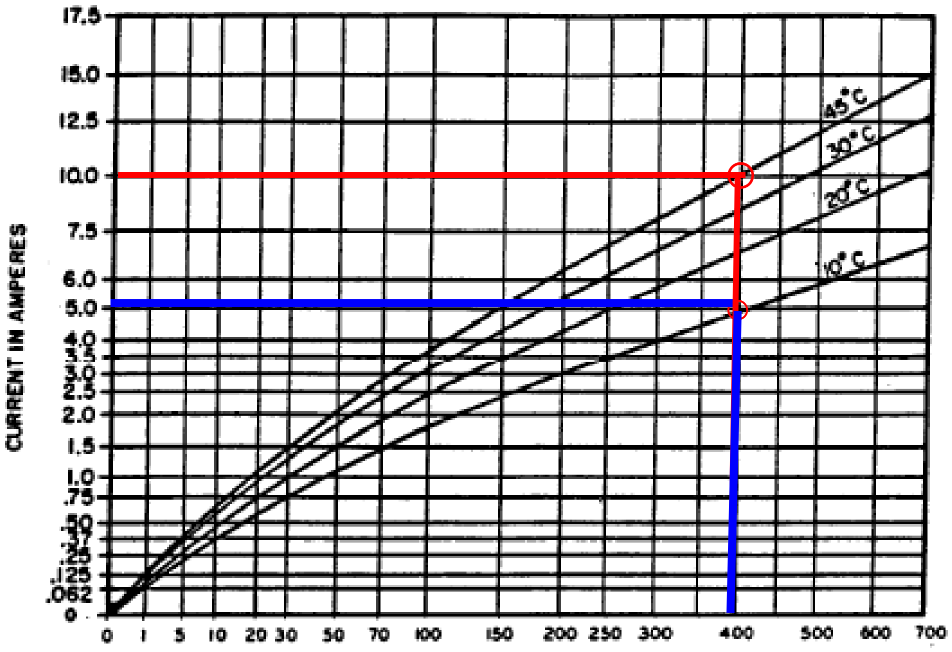
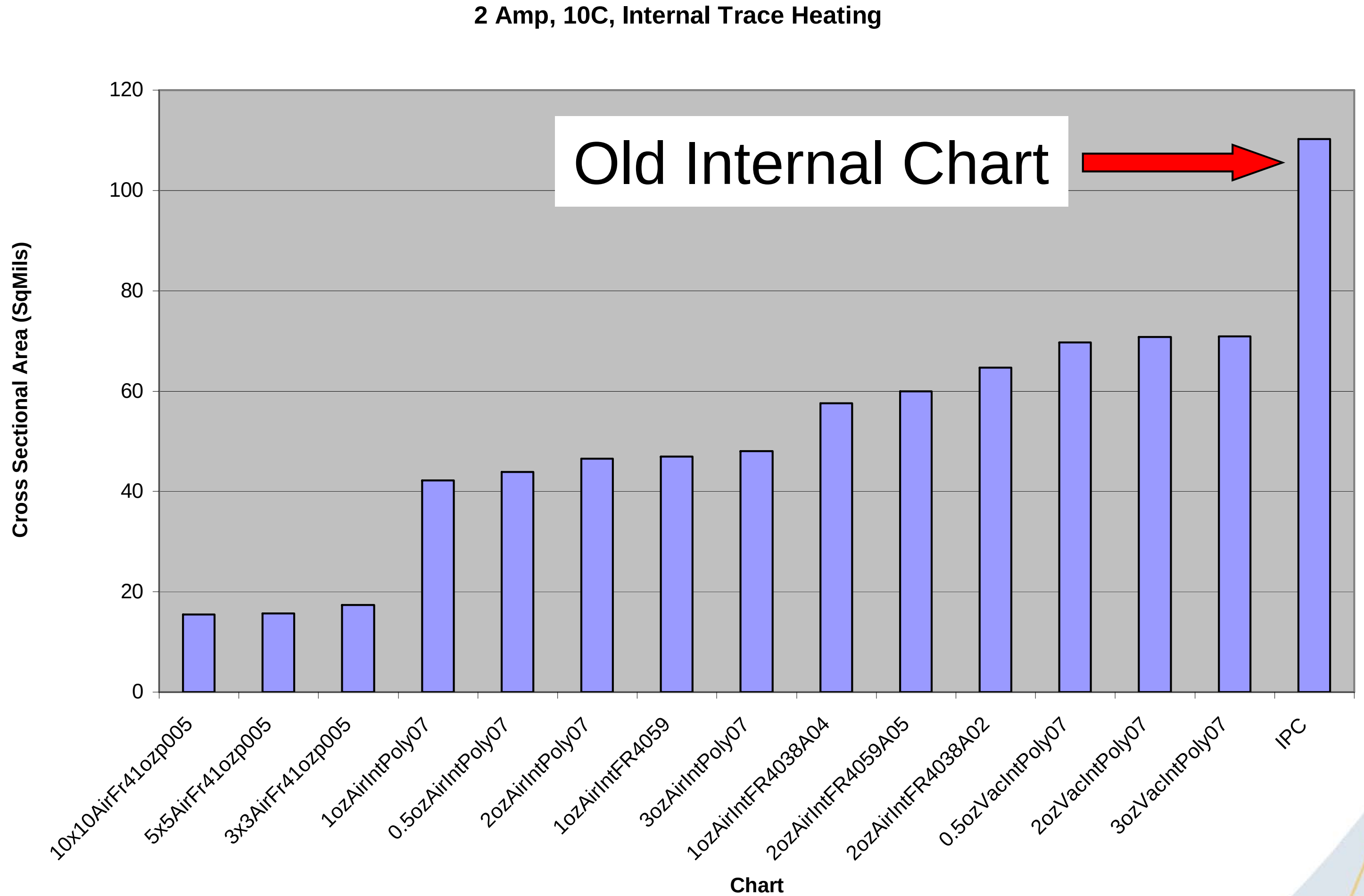
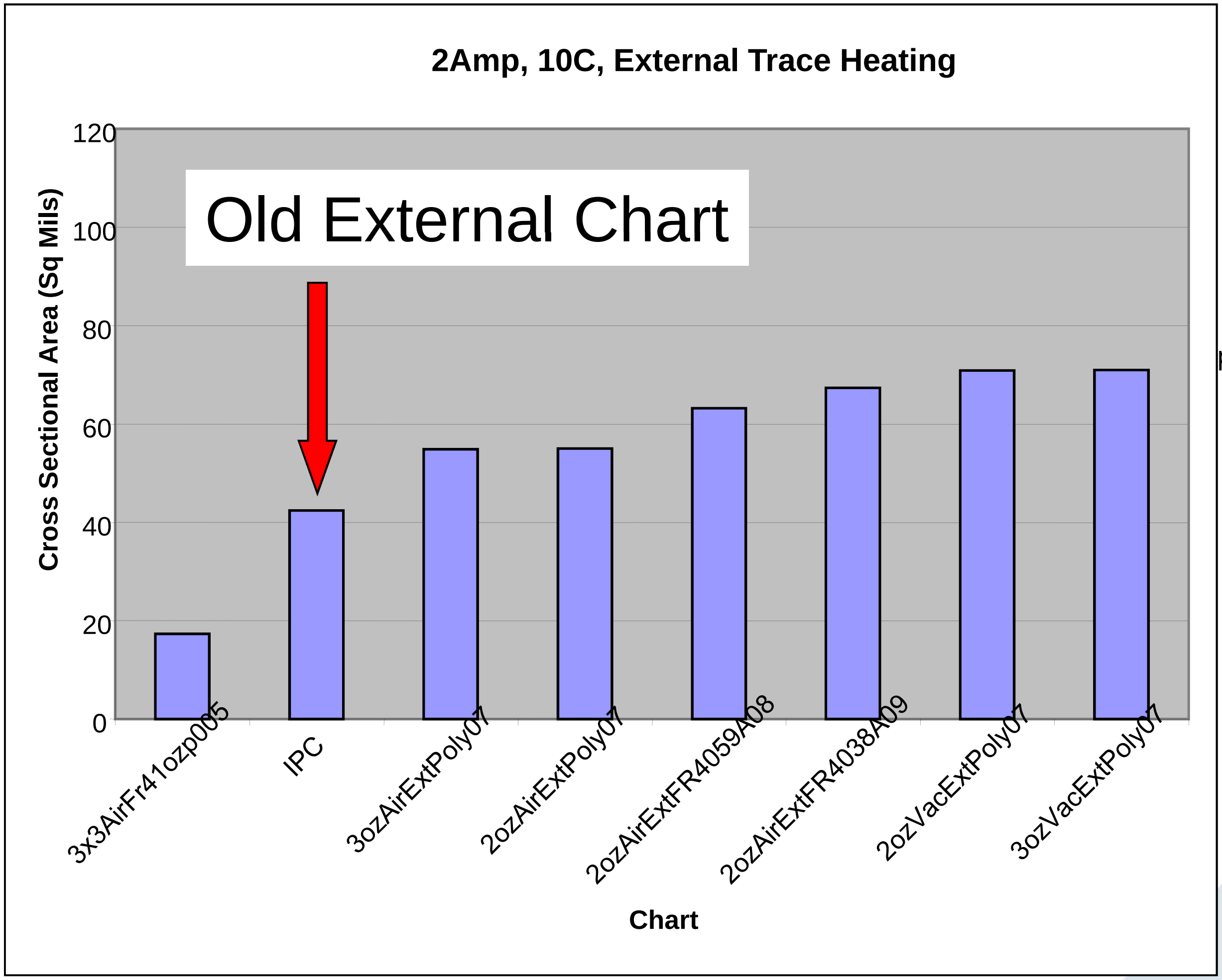


Figure C Internal Conductors

New Data Overview



New Data Overview



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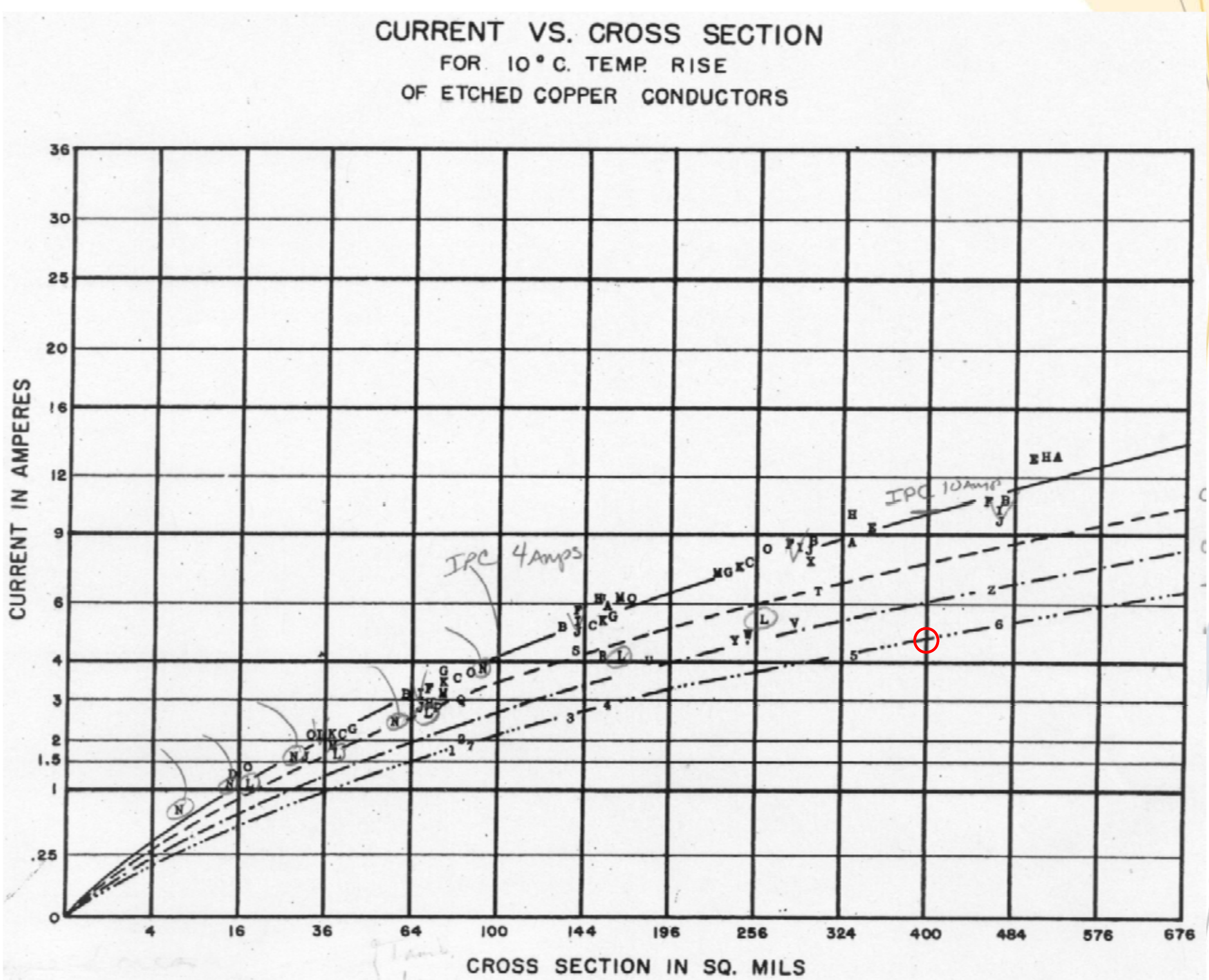
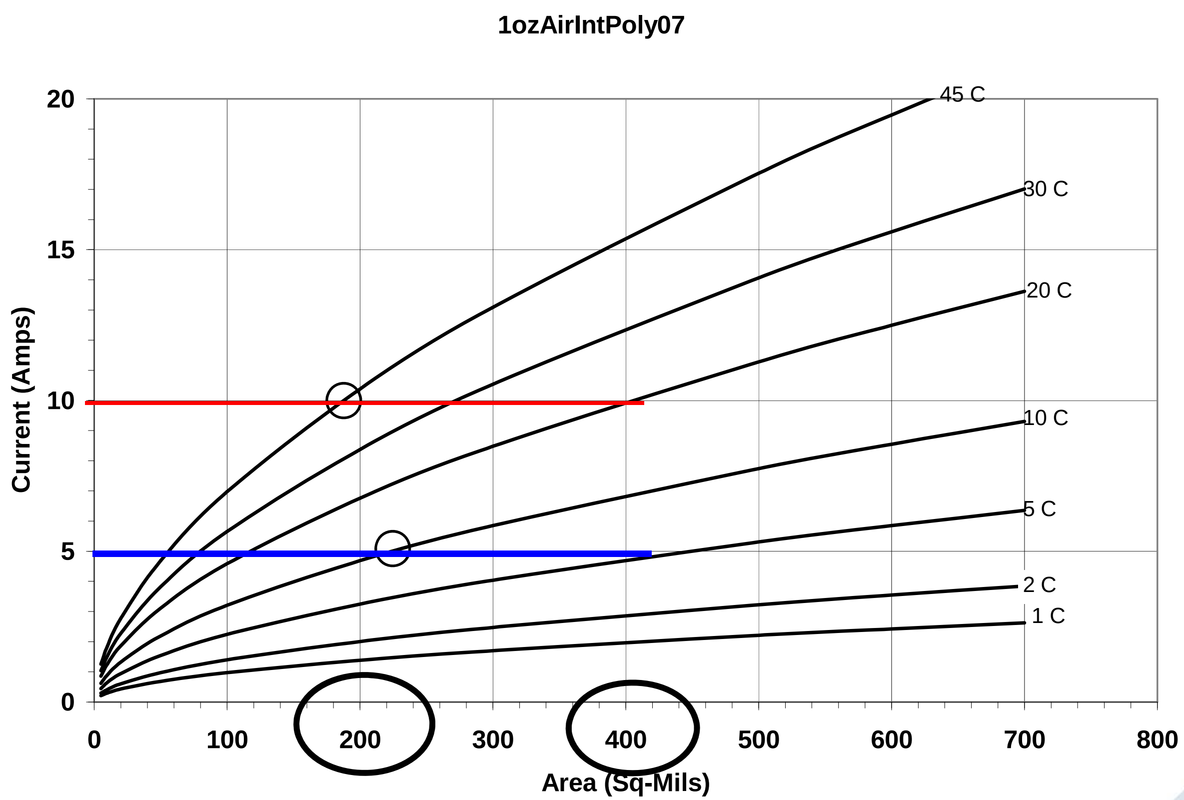
Old Guidelines

Original data: (National Bureau of Standards) Report #4283 “Characterization of Metal-insulator Laminates”, D.S. Hoynes, May 1, 1956. Commissioned by Navy Bureau of Ships.



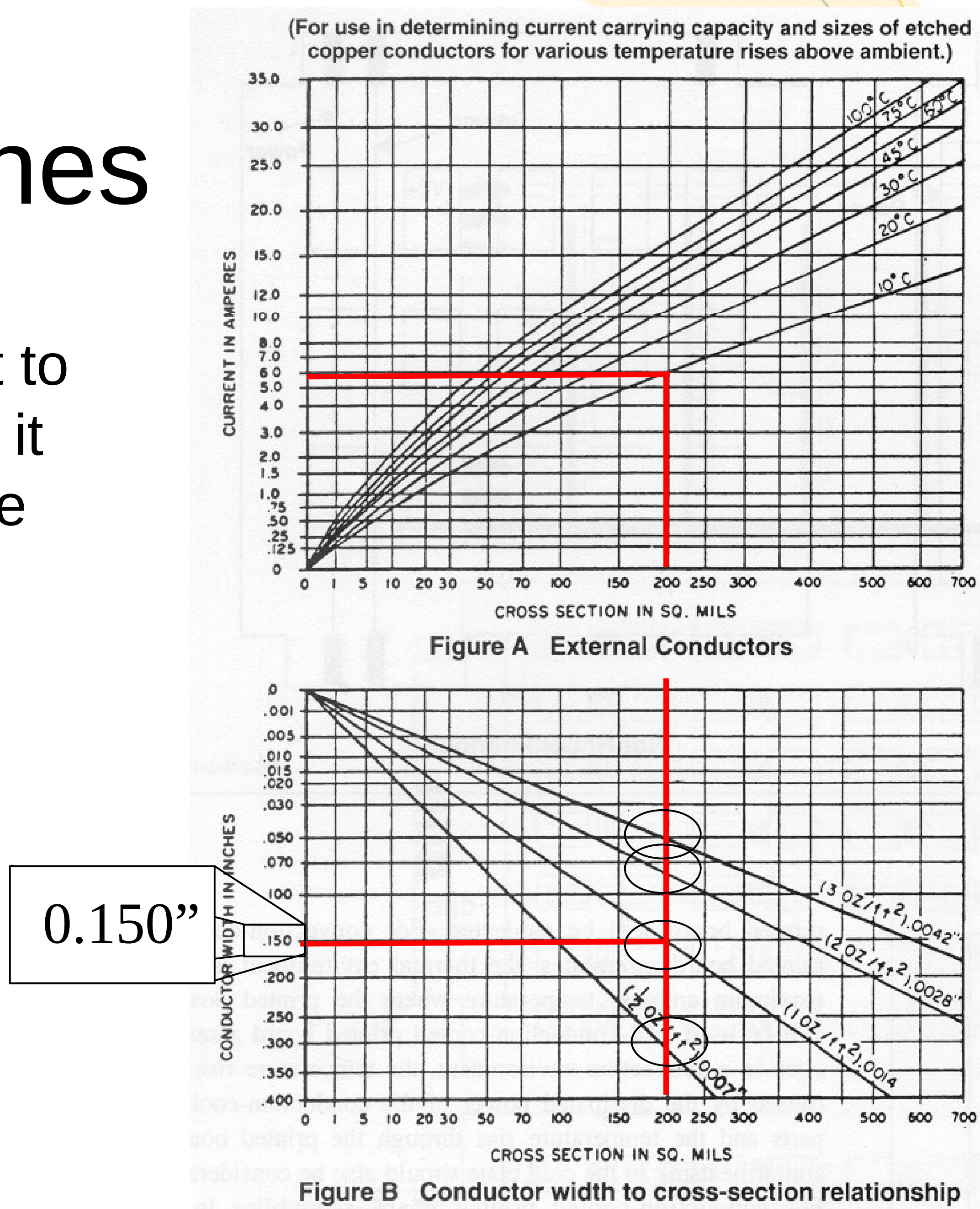
New Guidelines

- Being conservative gives up real estate.

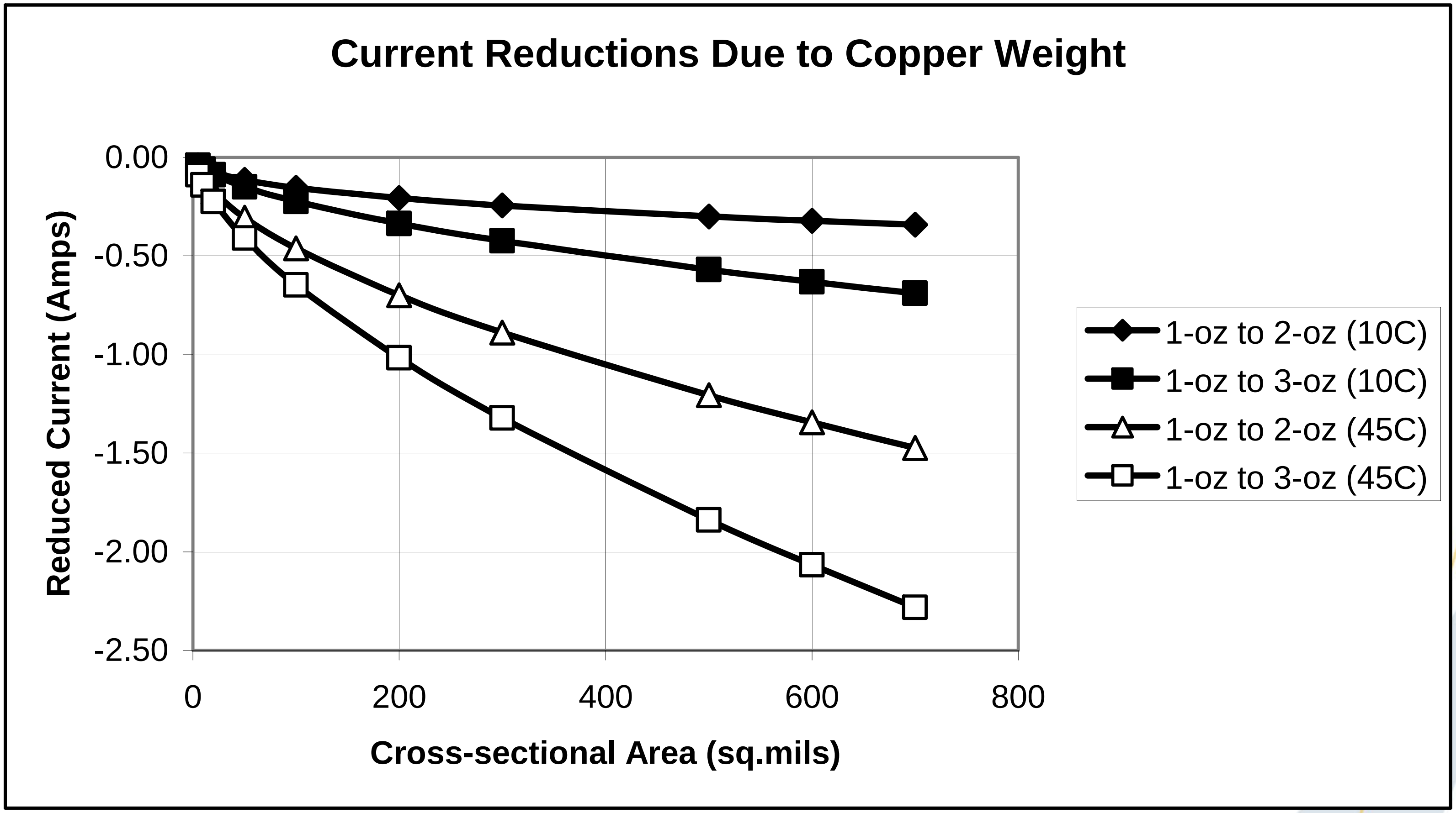


Old Guidelines

- It isn't as important to have guidelines as it is to understand the guidelines.
- Without an understanding one has no basis for thought.



New Guidelines



The Value of IPC-2152

- What defines conservative?
  1. Number of copper plane layers in the board
  2. Board mounting configuration
  3. Ambient environment
     1. Air (Forced Air – not included in IPC-2152 at this time)
     2. Vacuum
  4. Board thickness
  5. Board material
  6. Conductor thickness

- How does one go about creating a single standard for something that is so variable dependent?

The Value of IPC-2152

- Design optimization is company dependent.
  - Corporate design guidelines are dependent on the products being developed.
    - IPC-2152 offers methods for fine tuning design guidelines for product specific applications.
- It all begins with a baseline

The Value of IPC-2152

- The baseline is a 0.07-inch thick, polyimide printed circuit board, suspended in vacuum and free air.

The Value of IPC-2152

- **IPC-2152 and PRINTED CIRCUIT BOARD THERMAL MANAGEMENT**
- **CONDUCTOR SIZING DESIGN GUIDELINES**
- **CONDUCTOR SIZING CHARTS**
  - This is a discussion on the charts that are included in the main IPC-2152 document and the IPC-2152 appendix. New and old charts are presented along with an explanation of what they represent. There are basic charts that provide conservative results and new charts that allow design limits to be pushed to within the limits of a specific design. A discussion of these charts and how they were derived is presented.
- **SELECTING A CHART**
  - This is a discussion that provides the details of each of the charts presented in IPC-2152.
- **Conductor Temperature Rise**
  - This is a discussion on conductor temperature rise. I have been asked if the dielectric material glass transition temperature could be used to determine the maximum conductor temperature rise. My answer was that in all the designs that I've been involved, which expands over 20 years, that would be a disaster. This section is used for an open discussion on how that conductor temperature rise impacts the PCB thermal design.
- **How to Use the Charts**
  - This section is used to provide examples on how to use the charts depending on what information the designer has available. For example, if a minimum conductor size is required and the current level is known, what will be the resulting temperature rise.

The Value of IPC-2152

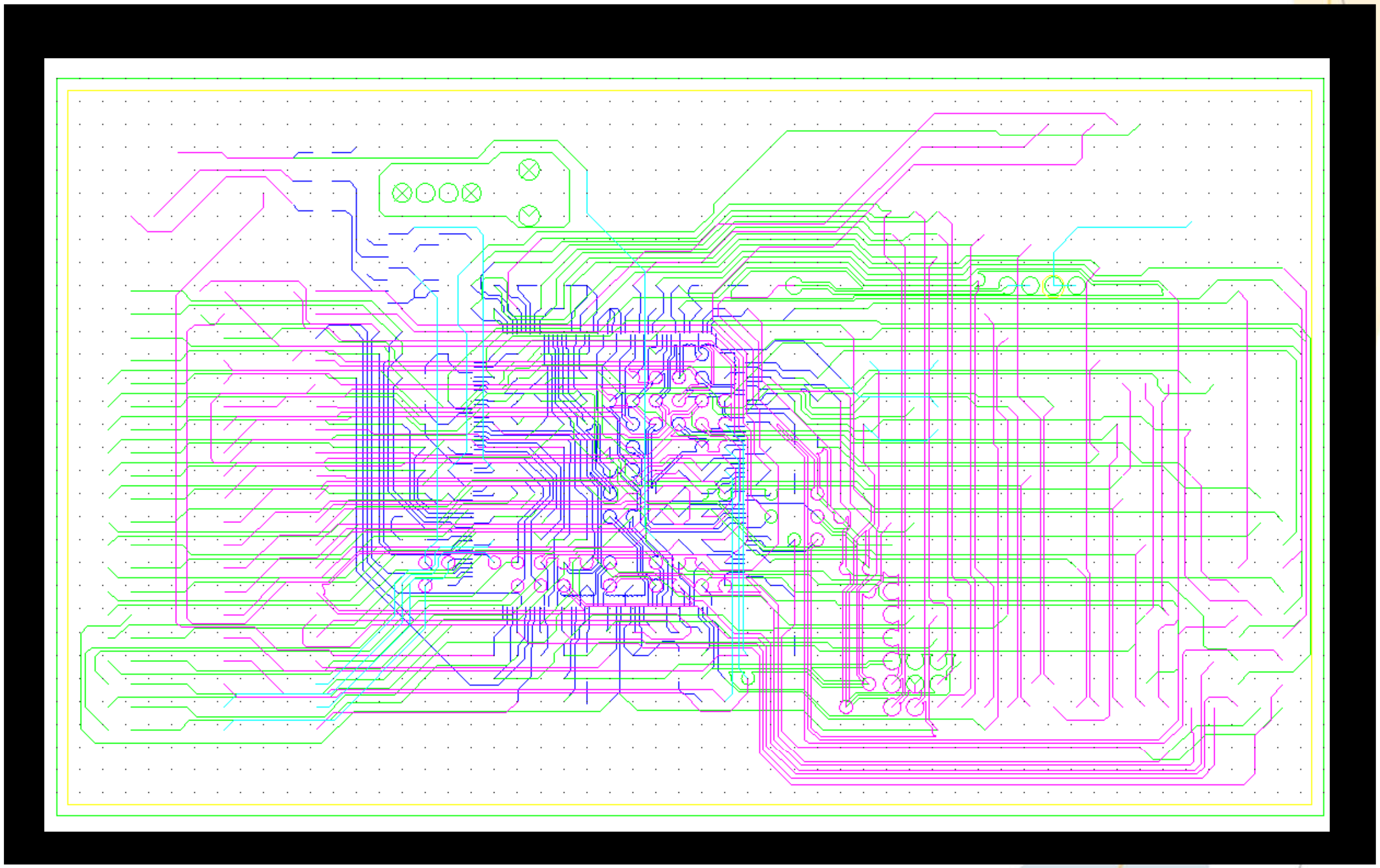
- **How to Use the Charts (cont.)**
  - Examples: Chart Basics: Known Current
- **Parallel Conductors**
  - Definition of parallel conductors and the importance of how these calculations impact conductor temperature rise.
  - **Etched Coils**
    - Etched coils are a variation of parallel conductors and an equation is presented to determine the temperature rise of a coil for an applied current.
- **Vias**
  - Sizing vias is discussed with respect to their temperature rise and how the charts apply to vias.
  - Conductor to Via to Plane
  - Thermal modeling of vias is presented to illustrate how heat transfer paths can impact the temperature rise of a via.
    - Microvia
    - A discussion is presented on microvias, filled and unfilled, with respect to temperature rise and applied current.
- **Flex Circuits**
  - Presently there are no charts specifically for flex circuits. Discussions that cover the variables that impact conductor temperature rise add to an understanding of what to expect for conductor temperature rise in flex circuits.

Parallel Conductors

- Full understanding of parallel conductor heating is necessary for taking advantage of IPC-2152.

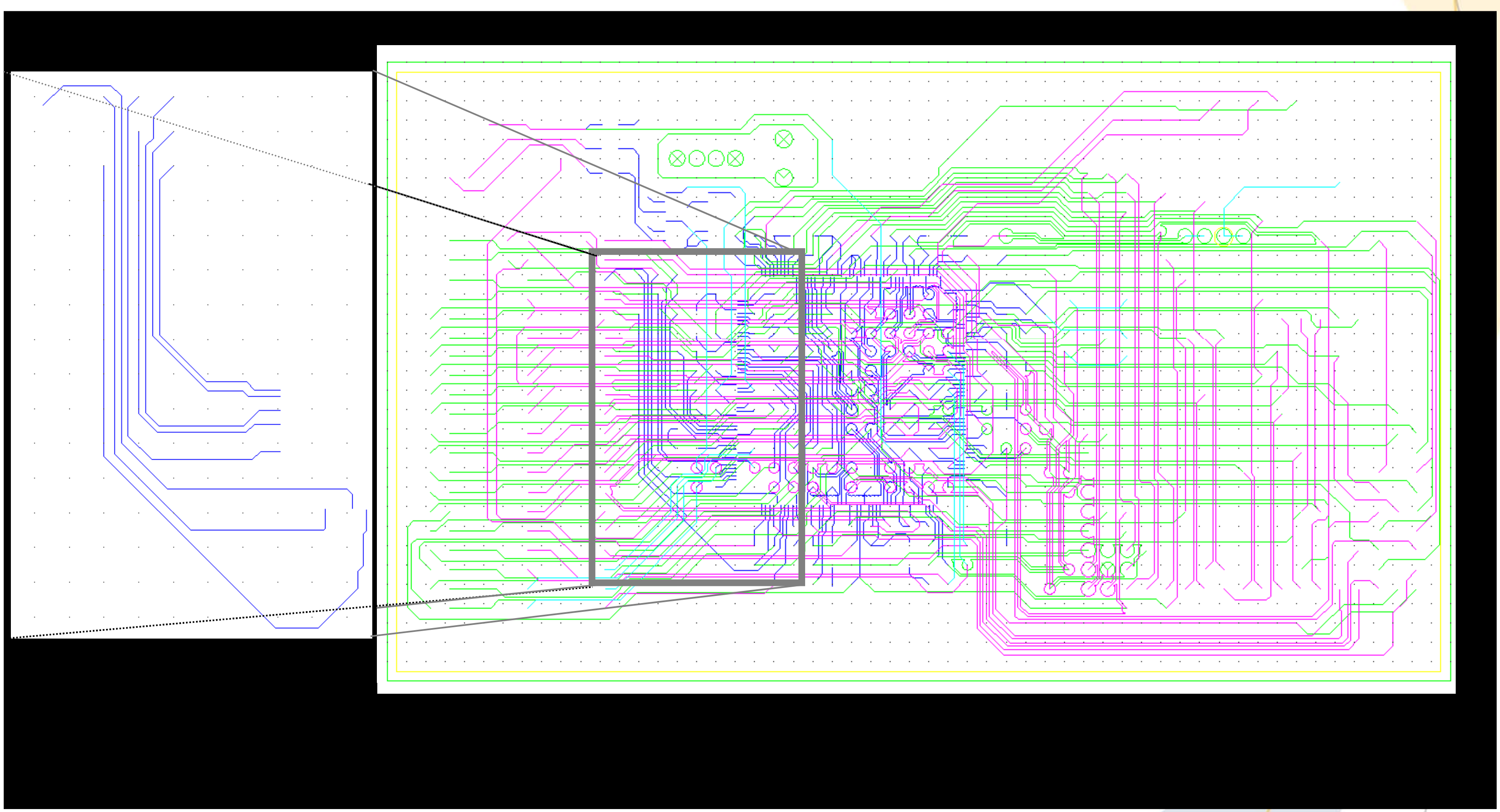
Parallel Conductors

<u>All layers</u> must be taken into consideration that have traces with applied current at the same time!



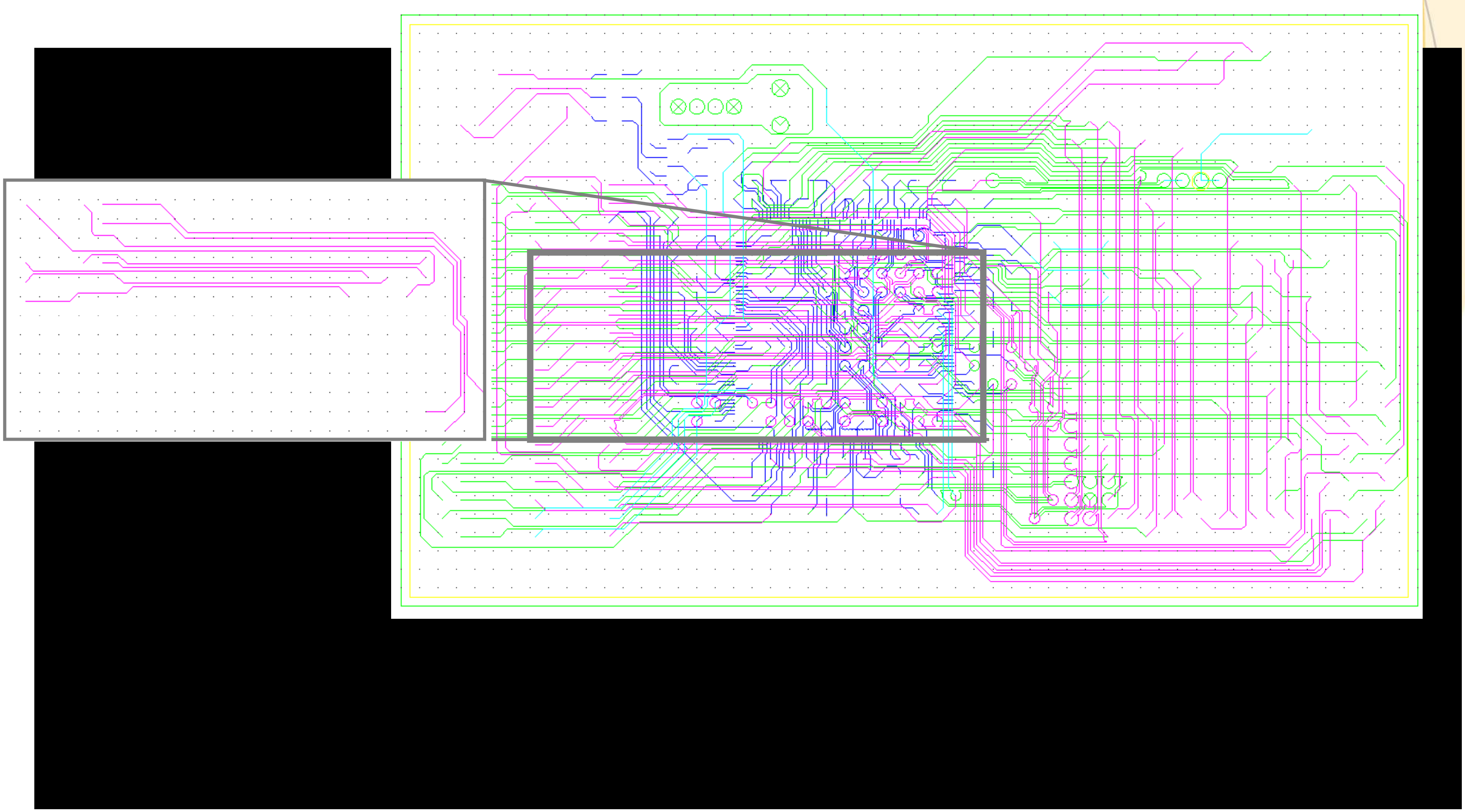
Parallel Conductors

External



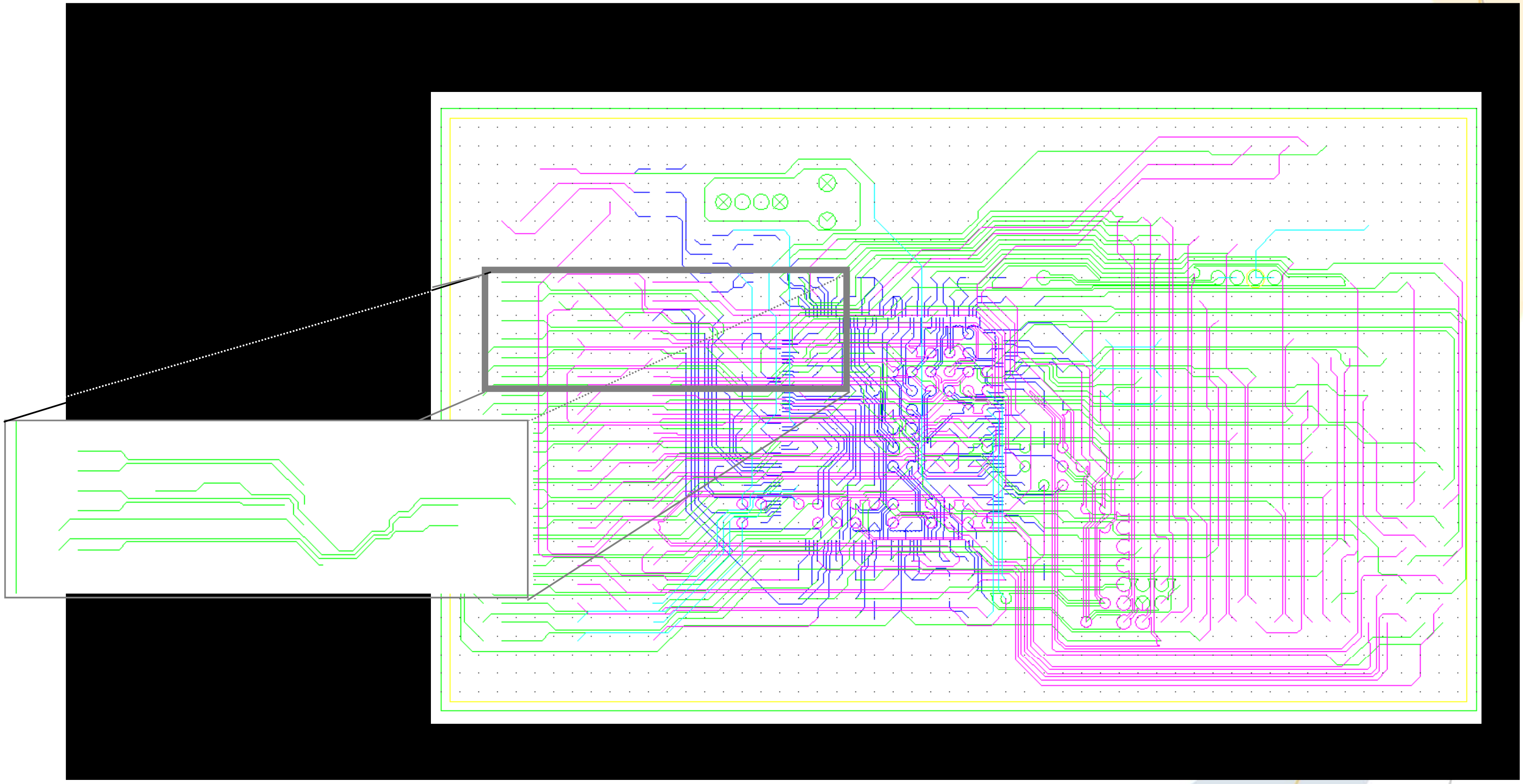
Parallel Conductors

Internal

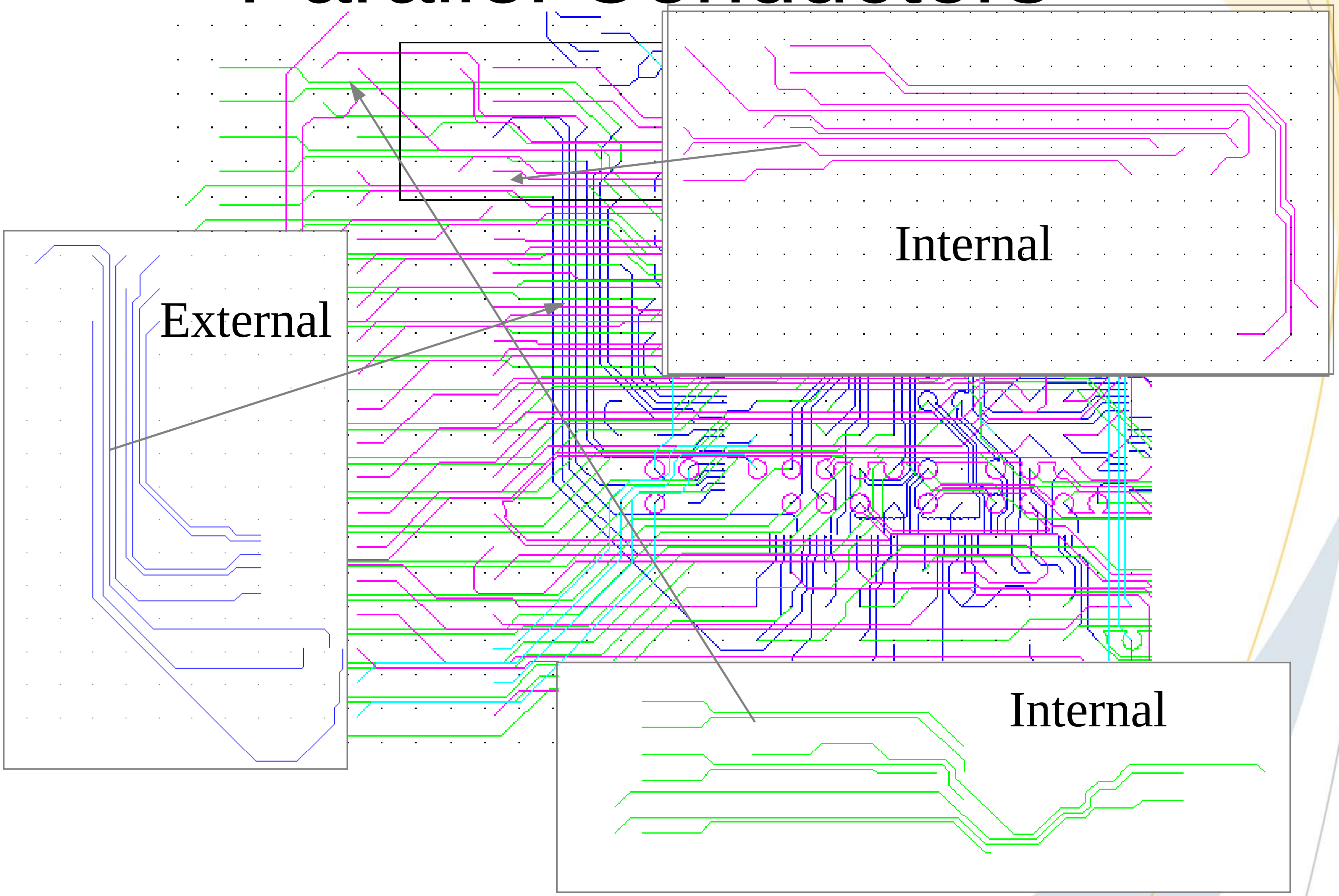


Parallel Conductors

Internal

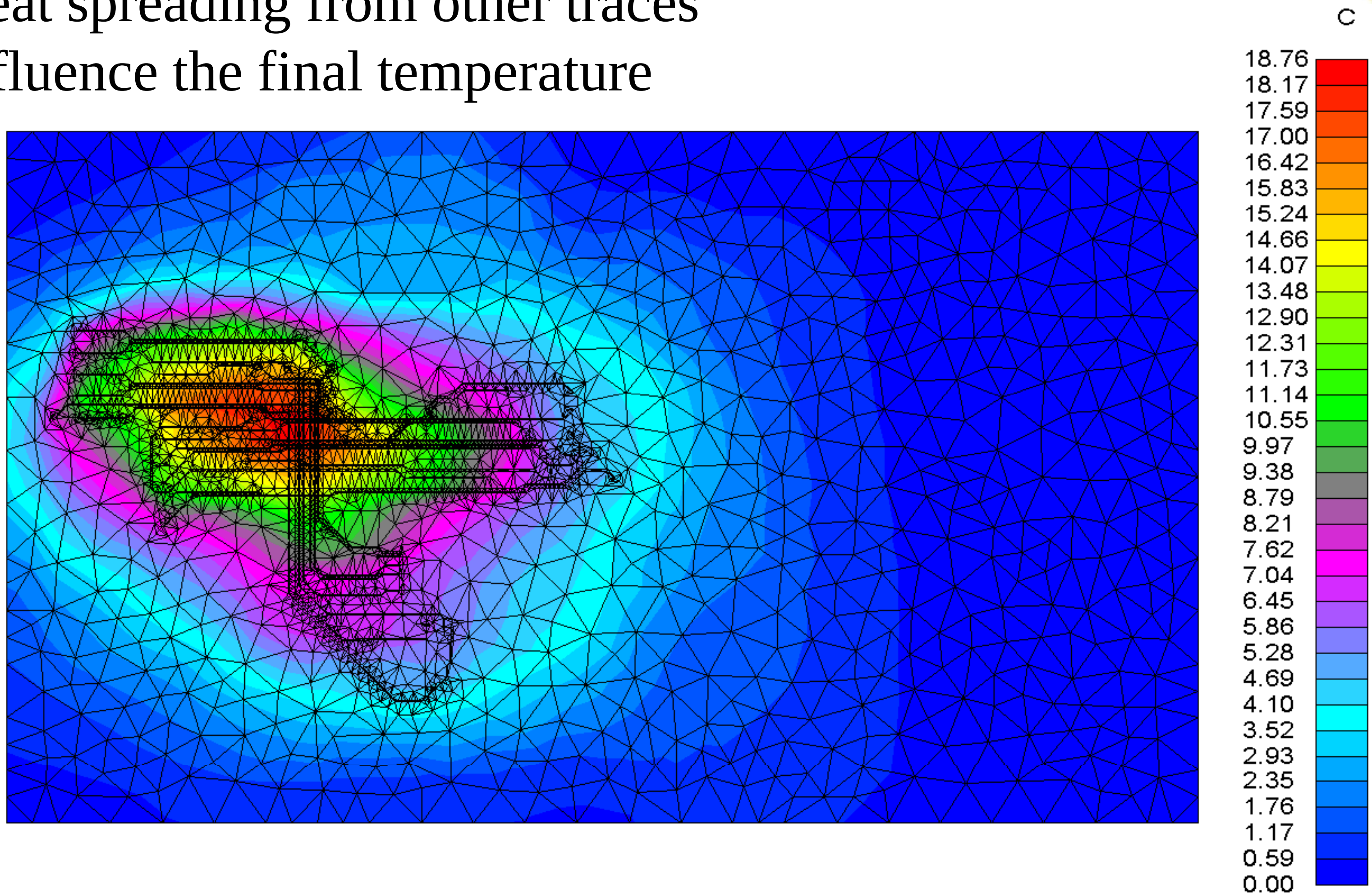


Parallel Conductors



Parallel Conductors

- Heat spreading from other traces influence the final temperature

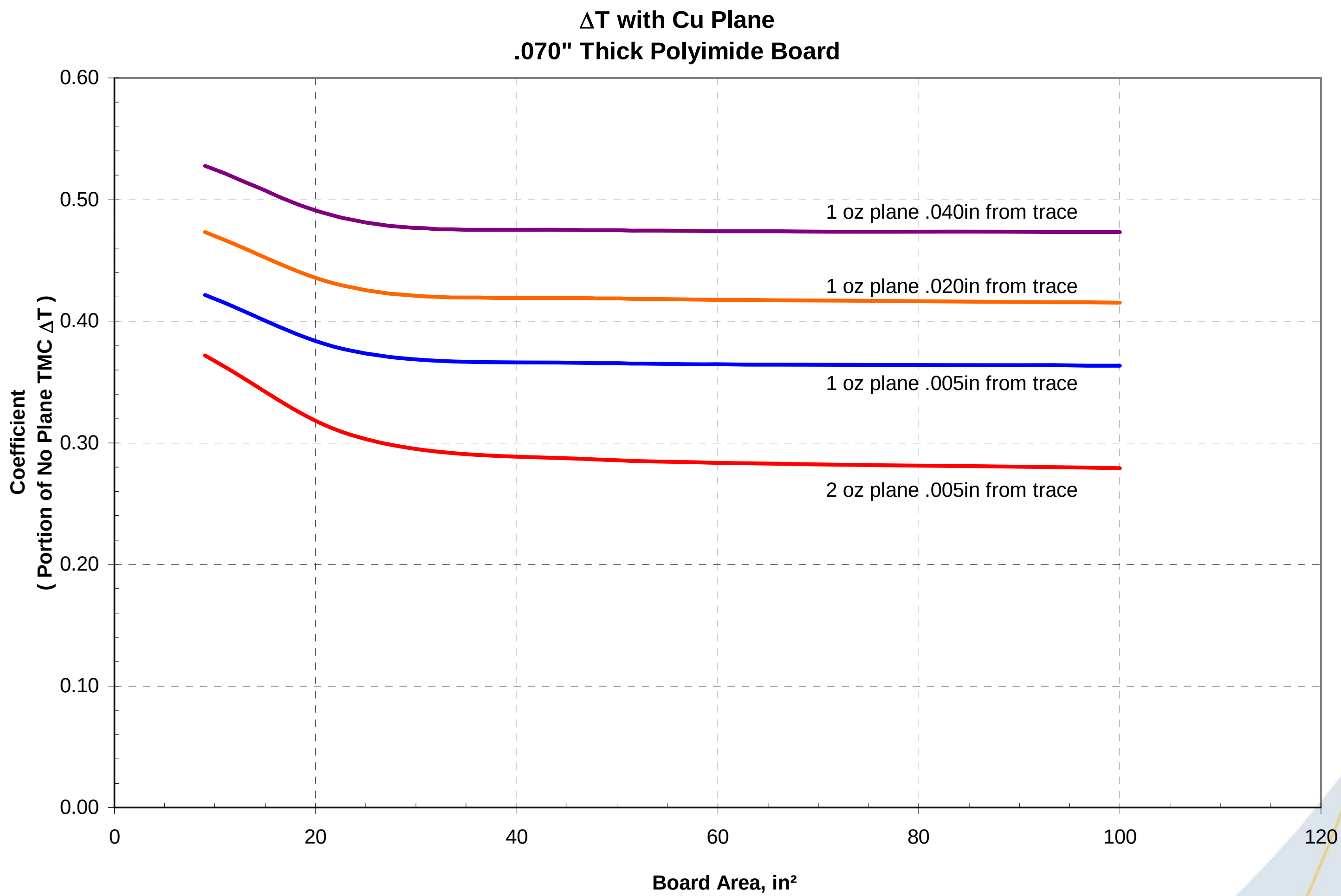


The Value of IPC-2152

Other Topics

- **PB Thickness**
  - A discussion is presented on how board thickness impacts conductor temperature rise.
- **Copper Weight**
  - A discussion is presented on how copper weight impacts conductor temperature rise. A point to contemplate is; for the same size conductor in terms of cross-sectional area, a conductor of 1-oz copper runs cooler than heavier weight coppers for the same applied current.
- **Board Material**
  - A discussion is presented on the board materials used to create the new charts and how to determine if new materials will cause a conductor temperature rise to increase or decrease.
- **Environments**
  - A discussion is presented on the environments, air and vacuum, that are represented in the new charts.
- **Copper Planes**
  - A discussion is presented on the impact that copper planes in a board design have on conductor temperature rise. This discussion includes how new charts were developed and how they are used to determine the impact of a single copper plane on conductor temperature rise. The discussion continues to expand on how the distance from a plane to the conductor impacts the conductor temperature rise.
    - Single Plane
    - Conductor Distance from Plane

Copper Planes



The Value of IPC-2152

Other TOPICS

- Additional topics that can be useful when managing the temperature rise of a conductor start to require analytical calculations.

- **Heat Transfer from a Conductor**
  - A discussion is presented on the calculations necessary to determine the heat transfer from a conductor.
- **Conductor Power Dissipation**
  - When calculating conductor temperatures it is essential to know the power that is lost in the conductor. A discussion is presented that covers the parameters necessary for determining conductor power losses.
  - **Conductor Electrical Resistance**
  - The electrical resistance of a conductor is required for determining the power losses in a conductor. A discussion is presented on several different copper resistivity values that are found in various sources such as the Handbook of Chemistry and Physics and how those values are different than measured conductor values.
- **Odd Shaped Geometries and Swiss-Cheese Effect**
  - A discussion is presented that covers a method for determining conductor temperature rise in odd shaped geometries. The following subtopics are used in this analytical method.
    - Voltage drop analysis
    - Voltage Sources
    - Current Source (or Sink)
    - Electrical Conductivity
- **HDI**
- Circuit board size, length and width, as well as thickness impact the temperature rise of a conductor. Fine line and space also impact the conductor temperature rise. A discussion is presented on how the limits size can be managed.
- **High-Speed**
  - A discussion is presented on calculating the skin thickness of a conductor and using the skin thickness to calculate the effective resistance in a conductor. The temperature rise of the conductor is discussed by using that effective resistance and calculated power dissipation.

The Value of IPC-2152

CONDUCTOR SIZING CHARTS

- A discussion is presented on all of the new charts and why there are so many and how in the future there will be even more.
  - Conductor Sizing Charts for Still Air Environments
    - Still Air Environment Charts in Imperial (Inch) Units
      - 3 oz. Conductor Sizing Charts, Still Air, External, Imperial (Inch) Units
      - 3 oz. Conductor Sizing Charts, Still Air, Internal, Imperial (Inch) Units
      - 2 oz. Conductor Sizing Charts, Still Air, External, Imperial (Inch) Units
      - 2 oz. Conductor Sizing Charts, Still Air, Internal, Imperial (Inch) Units
      - 1 oz. Conductor Sizing Charts, Still Air, Internal, Imperial (Inch) Units
      - ½ oz. Conductor Sizing Charts, Still Air, Internal, Imperial (Inch) Units
    - Still Air Environment Charts in SI (Metric) Units
      - 3 oz. Conductor Sizing Charts, Still Air, External, SI (Metric) Units
      - 3 oz. Conductor Sizing Charts Still Air, Internal, SI (Metric) Units
      - 2 oz. Conductor Sizing Charts Still Air, External, SI (Metric) Units
      - 2 oz. Conductor Sizing Charts Still Air, Internal, SI (Metric) Units
      - 1 oz. Conductor Sizing Charts Still Air, Internal, SI (Metric) Units
      - ½ oz. Conductor Sizing Charts Still Air, Internal, SI (Metric) Units
  - Conductor Sizing Charts for Vacuum/Space Environments
    - Vacuum/Space Environment Charts in Imperial (Inch) Units
      - 3 oz. Conductor Sizing Charts, Vacuum, Imperial (Inch) Units
      - 2 oz. Conductor Sizing Charts, Vacuum, Imperial (Inch) Units
      - ½ oz. Conductor Sizing Charts, Vacuum, Imperial (Inch) Units
    - Vacuum/Space Environment Charts in SI (Metric) Units
      - 3 oz. Conductor Sizing Charts, Vacuum, SI (Metric)
      - 2 oz. Conductor Sizing Charts, Vacuum, SI (Metric) Units
      - ½ oz. Conductor Sizing Charts, Vacuum, SI (Metric) Units

The Value of IPC-2152

- IPC-2152, Standard for Determining Current-Carrying Capacity in Printed Board Design
  - Begins with a baseline that provides a conservative method for sizing conductors for carrying current in printed circuits.
  - New charts included in IPC-2152 are based on tests conducted on traces in boards with no copper planes, suspended in still air as well as in vacuum.
  - The baseline represents a defined board thickness, board material, conductor width and thickness, as well as variations with respect to those variables.
- IPC-2152 is a technology enabler.
- Through the use of computer modeling and information within IPC-2152 and the IPC-2152 Appendix, current carrying capacity design guidelines can be optimized for any variation in printed circuit technology.
- Until the publication of IPC-2152 this was not possible with the available public information.

Questions?

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