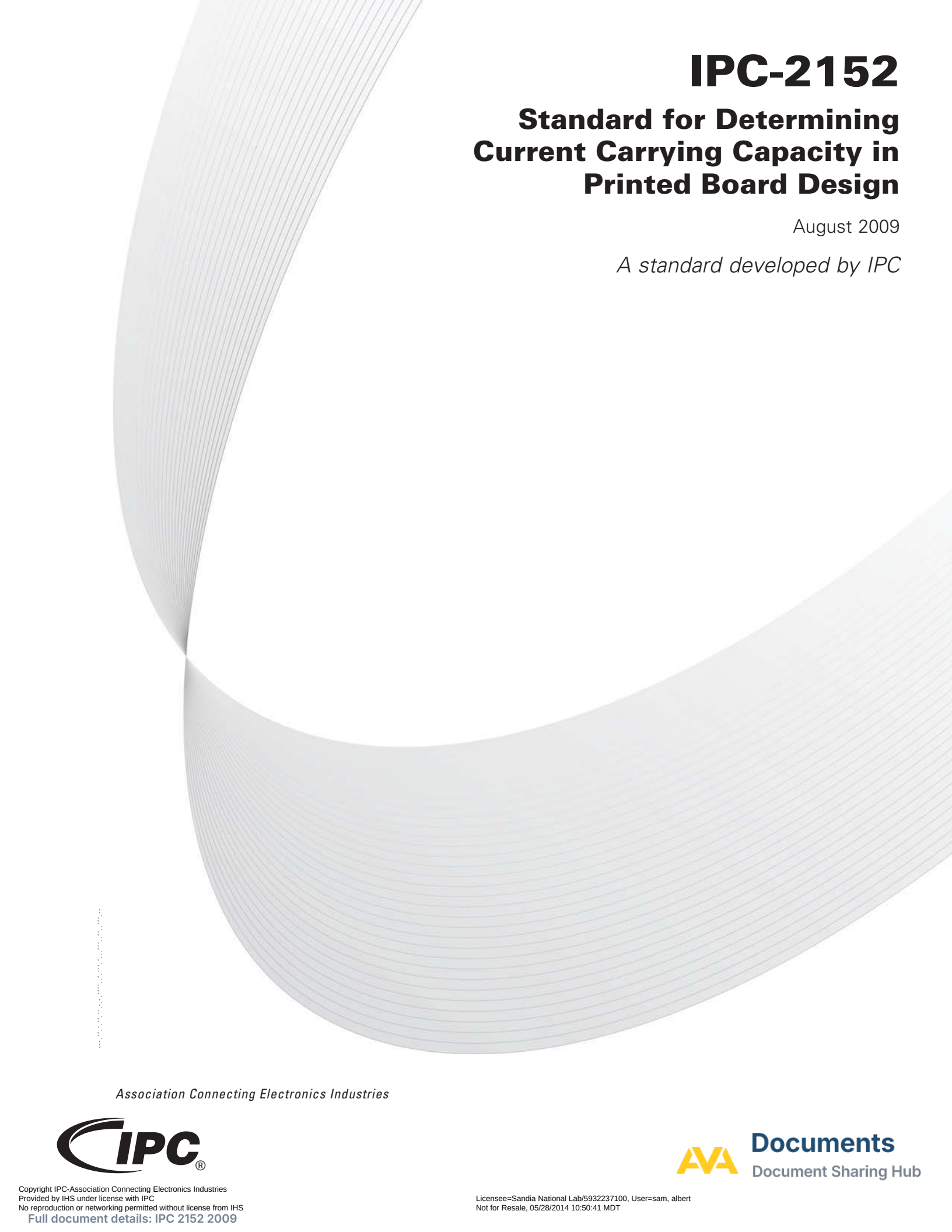




IPC-2152

Standard for Determining Current Carrying Capacity in Printed Board Design

August 2009

A standard developed by IPC

Association Connecting Electronics Industries



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IPC-2152

Standard for Determining Current Carrying Capacity in Printed Board Design

Developed by the Current Carrying Capacity Task Group (1-10b) of the
Printed Board Design Committee (1-10) of IPC

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Standard for Determining Current Carrying Capacity in Printed Board Design

1 SCOPE

This document is intended as a general guide to understanding the relationship between current, conductor size, and temperature, and can be used more specifically in the design and evaluation of copper conductors in printed boards (PBs).

1.1 Purpose The purpose of this document is to provide guidance on determining the appropriate conductor sizes on the finished PB as a function of the current carrying capacity required and the acceptable conductor temperature rise.

1.2 Presentation All dimensions and tolerances in this standard are expressed in hard SI (metric) units and parenthetical soft imperial (inch) units. Users of this standard are expected to use metric dimensions.

1.3 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.

1.4 Definition of Terms The definition of all terms used herein **shall** be in accordance with IPC-T-50 and as defined in 1.4.1 through 1.4.13.

1.4.1 Ambient The surrounding environment coming into contact with the system or component in question.

1.4.2 Base Material The insulating material upon which a conductive pattern may be formed (The base material may be rigid or flexible or both. It may be a dielectric or insulated metal sheet).

1.4.3 Circuitry Layer A layer of PB containing conductors, including ground and voltage planes.

1.4.4 Conductive Pattern The configuration or design of the conductive material on a base material. (This includes conductors, lands, vias, planes, and passive components when these are an integral part of the PB manufacturing process.)

1.4.5 Conductor Spacing The observable distance between adjacent edges (not center-to-center spacing) of isolated conductive patterns in a conductor layer.

1.4.6 Conductor Thickness Thickness of a conductor including additional metallic coatings but excluding non-conductive coatings.

1.4.7 Conductor Width The observable width of a conductor at any point chosen at random on a PB as viewed from directly above unless otherwise specified.

1.4.8 Convection Heat transfer that occurs at the interface of a solid and a fluid or gas that is due to their differences in temperature.

1.4.9 Copper Weight The mass of copper per unit area for a foil, typically expressed in ounces per square foot or grams per square centimeter (these units are not equivalent).

1.4.10 Current-Carrying Capacity The maximum electrical current that can be carried continuously by a conductor, without causing an objectionable degradation of electrical or mechanical properties of the product.



1.4.11 Heat Sink Plane A continuous sheet of metal on or in a PB that functions to dissipate heat away from heat generating components.

1.4.12 Thermal Conductivity The property of a material that describes the rate at which heat will be conducted through a unit area of the material for a given driving force.

1.4.13 Thermal Resistance The resistance of a material to the passage of thermal energy, usually measured in degrees °C/W.

2 APPLICABLE DOCUMENTS

The following documents, of the issue currently in effect, form a part of this document to the extent specified herein.

2.1 IPC¹

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

IPC-A-600 Acceptability of Printed Boards

IPC-2221 Generic Standard on Printed Board Design

IPC-6012 Qualification and Performance Specification for Rigid Printed Boards

IPC-TM-650 Test Methods Manual²

2.5.4.1 Conductor Temperature Rise Due to Current Changes in Conductors

3 CONDUCTOR SIZING INTRODUCTION

A PB consists of one or more layers of conductive material (usually copper) separated or supported by layers of insulating base material. When a circuit is energized, current flowing through the conductors generates heat, which creates a temperature rise in the conductor and the surrounding area. The conductor temperature rise, also referred to as delta T (ΔT), is the conductor temperature compared to the local PB temperature.

When current is applied to a conductor, its temperature rise is dependent upon its cross sectional area and factors such as the PB thickness, PB material, amount and adjacency of copper in the PB, and the environment in which the PB is being operated. The mounting of the PB, environment (air, vacuum, forced air), copper plane layers, the components that the conductor is connected to, and length of the conductor are a partial list of the things that can impact the conductor temperature rise. It is not feasible to assemble charts that address all of these concerns. Therefore, charts are presented that take into account a wide spectrum of design concerns that bound most PB designs used in still air and vacuum environments.

The conductor temperature rise, calculated using the charts in this document and in Appendix A, is one contribution to the overall temperature rise of the electronics system. Components on the PB will contribute to the PB temperature rise. Many other contributions to the PB temperature rise may occur in a particular application. When considering the ambient temperature, with respect to the charts in this document, one must evaluate all the contributions to the overall temperature rise of the PB in the worst case use conditions in which it is required to operate.

4 CONDUCTOR SIZING DESIGN GUIDELINES

The following guidelines may be used for determining conductor width, conductor thickness, cross-sectional area, and current-carrying capacity with respect to temperature rise.

- a) For the conductor being evaluated, it is assumed that the conductor surface area is relatively small compared to the adjacent free PB area and that the PB area is 76.2 x 76.2 mm [3.0 x 3.0 in] or greater. Reducing the PB size, as well as the PB thickness, increases the conductor temperature rise.

Note: The reference PB size is 366 x 142 x 1.79 mm [14.4 x 5.6 x 0.07 in].

- b) It is assumed that the PB thickness is between 1.52 mm [0.06 in] and 1.79 mm [0.07 in]. PBs less than 1.52 mm [0.06 in] in thickness will have a higher temperature rise than those represented by the charts in 5.1 and 5.2. Reducing the PB

1. www.ipc.org

2. Current and revised IPC Test Methods are available on the IPC Web site (www.ipc.org/html/testmethods.htm)

thickness from 1.79 to 1.02 mm [0.07 to 0.04 in] results in an increase in the ΔT by an approximate factor of 1.4. See A.4.2 of Appendix A for further discussions regarding the effect of temperature rise and PB thickness.

- c) The curves in Section 5 are not derated; they represent the temperature rise of a single conductor in a PB, as described in Section 3. When estimating the conductor cross-sectional area, consideration should be given to allow for material and process variations, such as undercut and final copper thickness. To account for process variations, a smaller cross-sectional area should be used. See IPC-2221 or IPC-A-600 for discussion on etched conductor characteristics.

The thickness of copper after processing has a minimum allowable value (see IPC-6012 or procurement documentation).

- d) As far as other design constraints allow, conductors should be sized to keep the temperature rise to a minimum. The conductor temperature rise, otherwise referred to as the ΔT , will be the temperature rise above the local PB temperature surrounding the conductor. Components and other conditions will drive the PB to temperatures above the surrounding environmental temperature. For example, if the PB is at 75 °C during operation and the conductor is sized for a 10 °C rise, then the conductor temperature will be 85 °C.

NOTE: The increase in electrical resistance of the conductor due to an elevated temperature is a secondary effect on conductor temperature rise. See A.5.2.1 of Appendix A for an example that shows the change in resistance of a conductor with respect to temperature rise.

- e) For isolated conductor applications the charts in Section 5 may be used directly. For groups of *parallel conductors*, if closely spaced, the temperature rise may be found by using an equivalent cross-section and an equivalent current. The following apply to parallel conductors:
 - 1) Parallel conductors refer to adjacent conductors on the same layer and on adjacent layers.
 - 2) Adjacent conductors within 25.4 mm [1.0 in] can affect the temperature rise. This means that, for many PBs, all conductors are thermally linked and need to be considered as such.
 - 3) The equivalent cross-section is equal to the sum of the cross-sections of the parallel conductors.
 - 4) The equivalent current is the sum of the currents in the conductors.

See A.3.3 of Appendix A for computer generated simulations that illustrate the temperature distribution around heated conductors.

- f) For conductors with cross-sectional areas greater than 452 mm² [0.700 in²], extrapolating the charts in Section 5 is not recommended without first performing a thermal analysis of the application.

5 CONDUCTOR SIZING CHARTS

Charts have been developed as estimation tools to predict the relationship between current, conductor size and temperature rise. If more accurate predictions are needed than these charts are capable of providing, a thermal analysis based on the specific parameters of the design may be necessary.

The charts included in this document represent copper conductors in a polyimide or FR-4 epoxy resin based PB without copper plane layers. This configuration is consistent with IPC-TM-650, Method 2.5.4.1. Variations from this baseline configuration are discussed in Section A.3 and A.4.4 of Appendix A. The charts presented in this document, for most cases, will predict higher temperatures than the actual conductor will experience for a specific current level. A discussion is included in section A.2 and A.4.6 of Appendix A on the topic of temperature margins that can exist using the charts.

Multiple charts are presented for each set of parameters for sizing electrical conductors. These charts are presented as an aid to increase the level of precision when determining the temperature rise of a conductor or group of conductors. If a more precise estimate of the conductor temperature rise is needed, see Appendix A for further information.

The universal chart in Figure 5-1 is recommended for sizing all conductors, both internal and external, in all environments, subject to the guidelines provided in Section 4. Results from this chart are dependable but very conservative, resulting in conductor sizes that may be greater than needed for many applications. The series of charts following 5-1 are provided for when design constraints require a more accurate estimation.

The charts in 5.1 are recommended for sizing both internal and external conductors in air environments when smaller conductor sizes are needed than those sized using Figure 5-1.

The charts in 5.2 are recommended for both internal and external conductors in vacuum environments when smaller conductor sizes are needed than those sized using Figure 5-1.

Review A.7.1 of Appendix A for details regarding the origin of these charts and further discussion on conductor temperature rise from an applied current.

How to Use the Chart in Figure 5-1 The charts require knowing two of three variables: desired continuous current, acceptable conductor temperature rise, or conductor cross-sectional area. If any two of these are known, the third can be approximated.

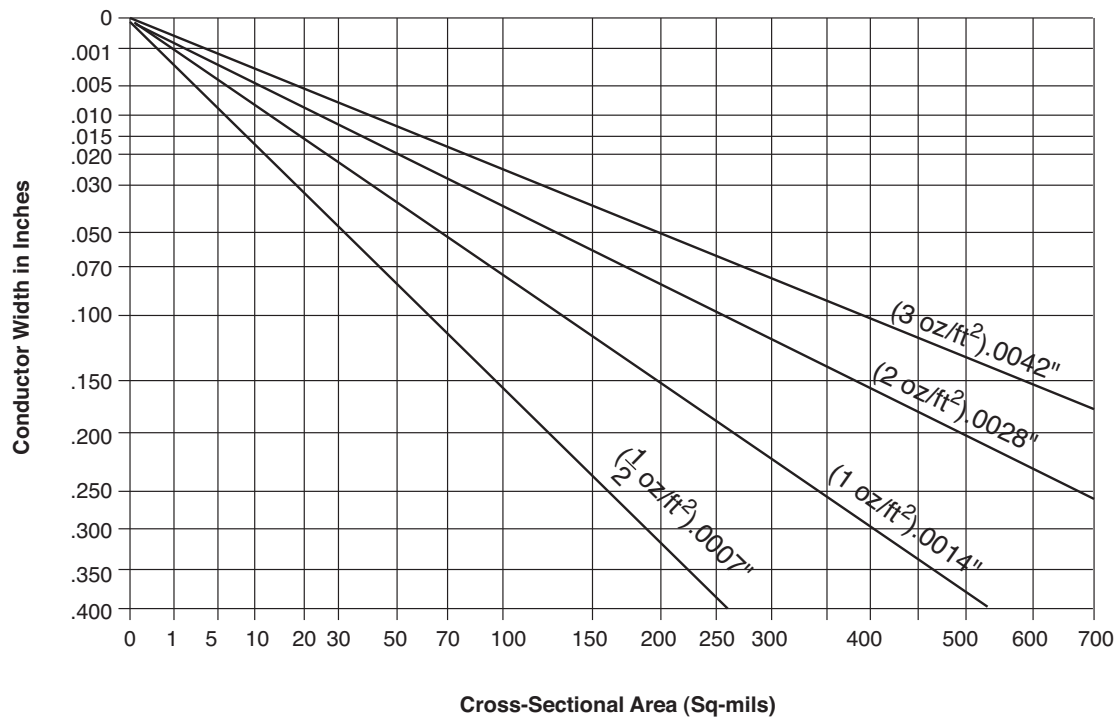
For example, if a conductor must carry 5 amps with a maximum temperature rise of 10 °C, what is the appropriate conductor width?

On the lower chart in Figure 5-1, find the “5-amp” line on the vertical axis, and follow it across until it intersects the 10 °C curve. Follow the line at that intersection down to the axis to find the appropriate cross-sectional area of the conductor (400 sq-mils).

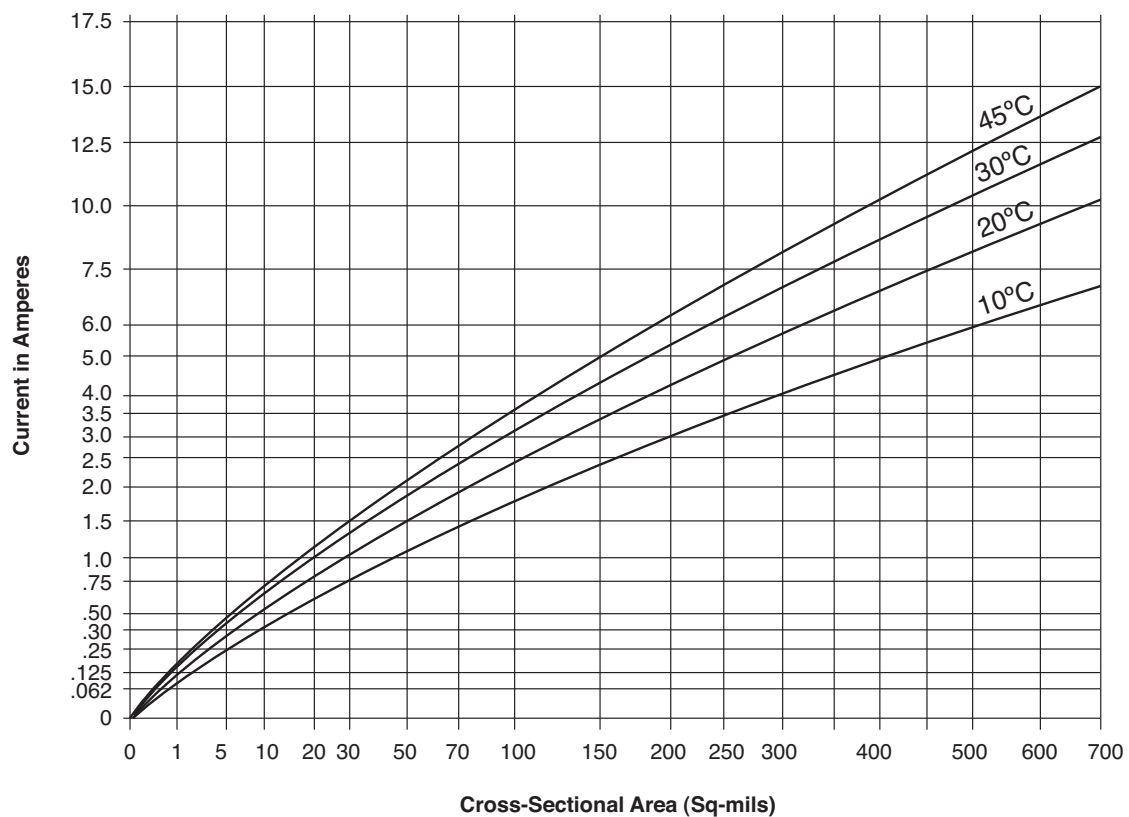
Then, move to the upper chart in Figure 5-1, which shows the relationship between cross-sectional area and conductor width and thickness. Assume the PB design is going to use 1 oz. copper layers. To find the appropriate conductor width, use the same 400 sq-mil line and follow it to where it crosses the 1 oz. copper curve. Finally, follow the line intersecting the 1 oz. copper curve back to the axis labeled “Conductor Width In Inches” to find that the conductor width should be 0.30 in. Work in reverse to find the maximum current if the conductor width is known.

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Conductor width to cross-section relationship



IPC-2152-5-1

Figure 5-1 Internal and External Conductors (All Environments)

5.1 Conductor Sizing Charts for Still Air Environments

5.1.1 Still Air Environment Charts in Imperial (Inch) Units Figure 5-2 through Figure 5-5 represent charts for internal and external conductors in still air environments in imperial (inch) units.

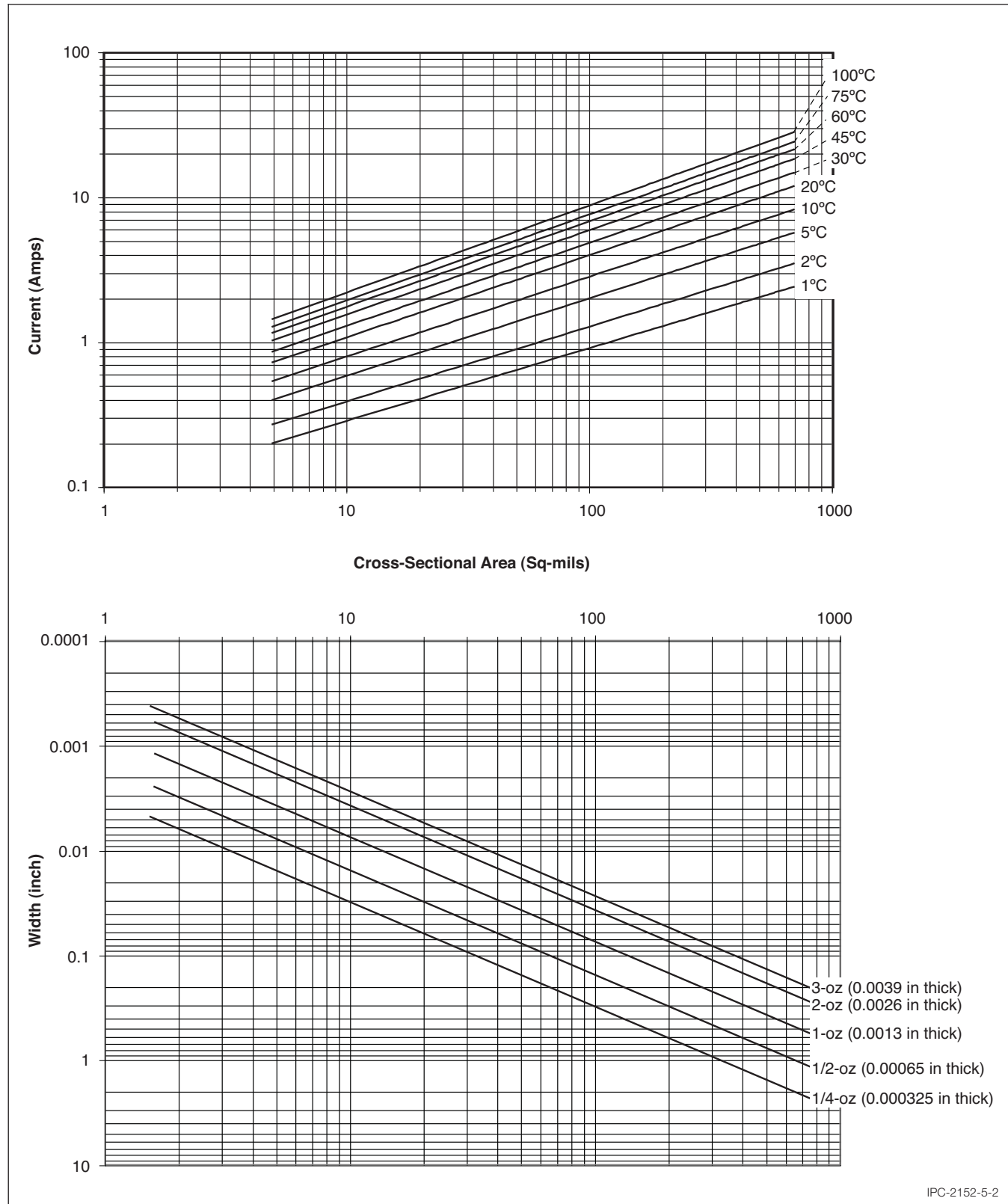


Figure 5-2 Internal and External Conductors (Still Air) (5-700 Sq-mils)



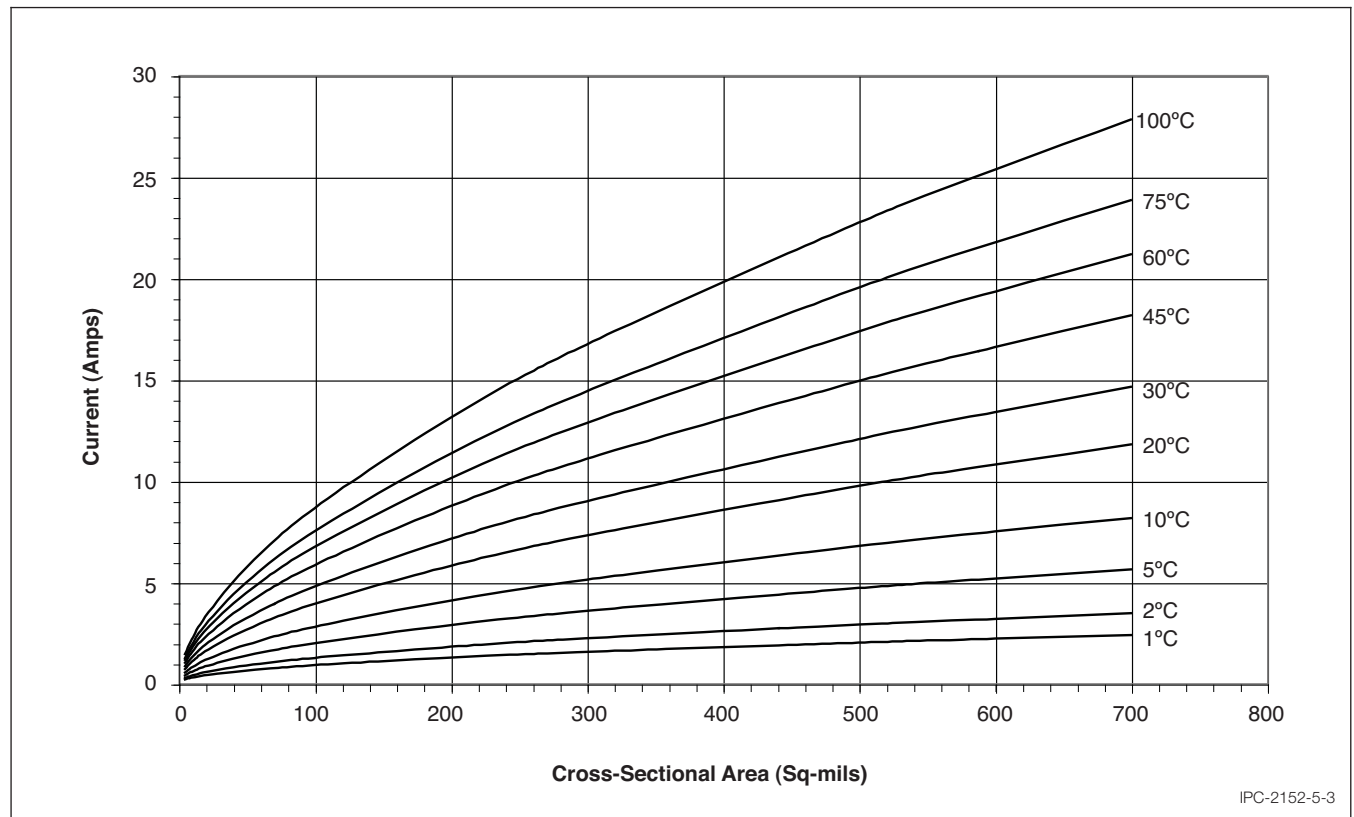


Figure 5-3 Internal and External Conductors (Still Air) (5-700 Sq-mils)

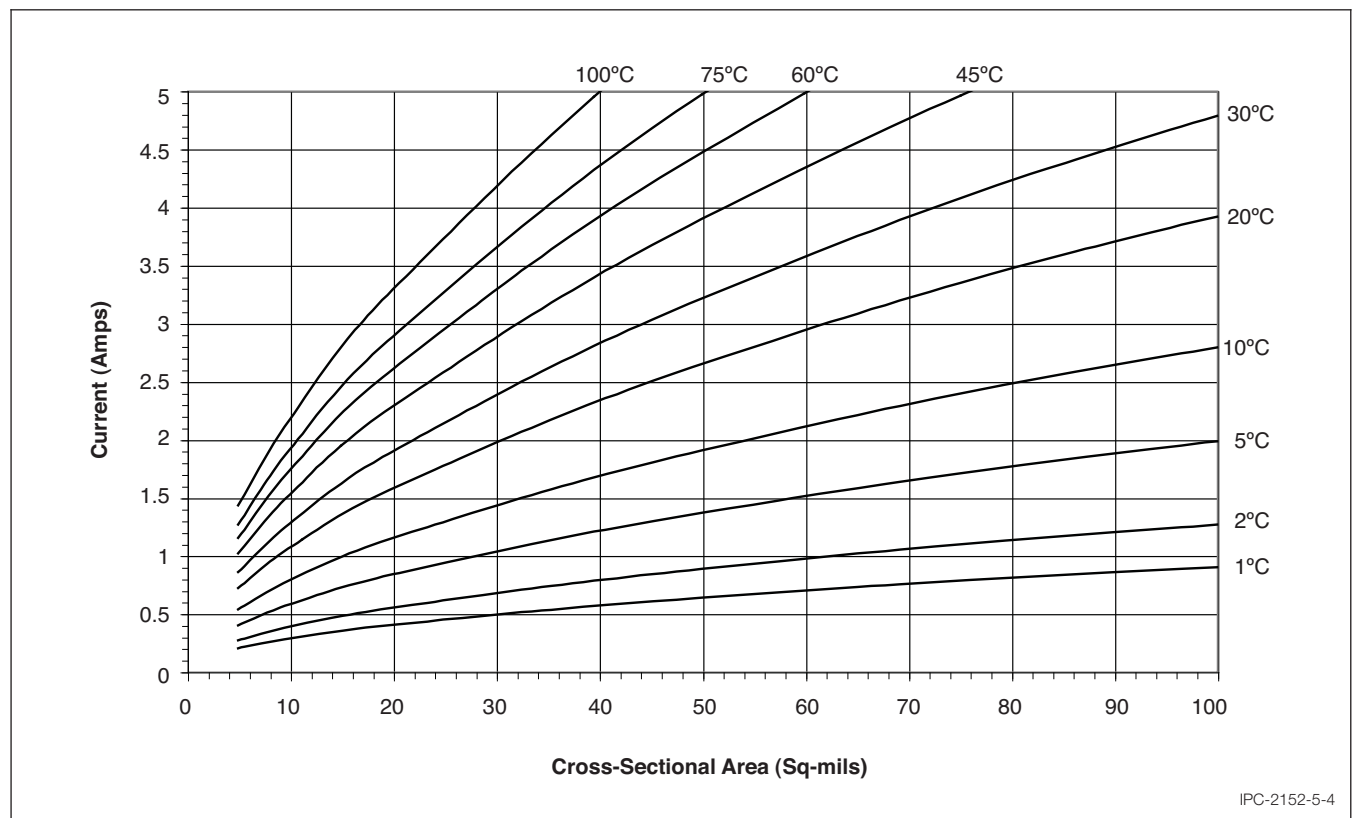


Figure 5-4 Internal and External Conductors (Still Air) (5-100 Sq-mils)

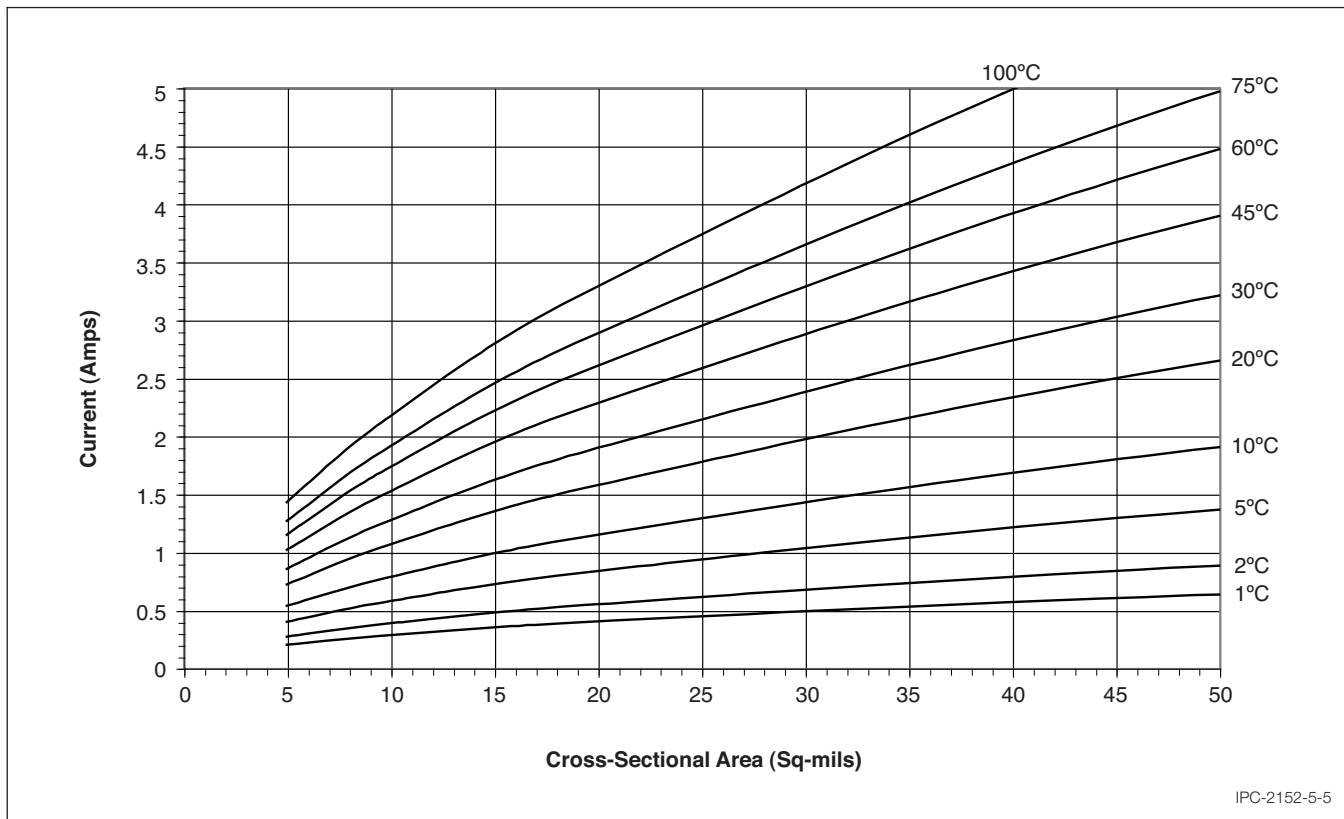


Figure 5-5 Internal and External Conductors (Still Air) (5 - 50 Sq-mils)

5.1.2 Still Air Environment Charts in SI (Metric) Units Figure 5-6 through Figure 5-9 represent charts for internal and external conductors in still air environments in SI (metric) units.

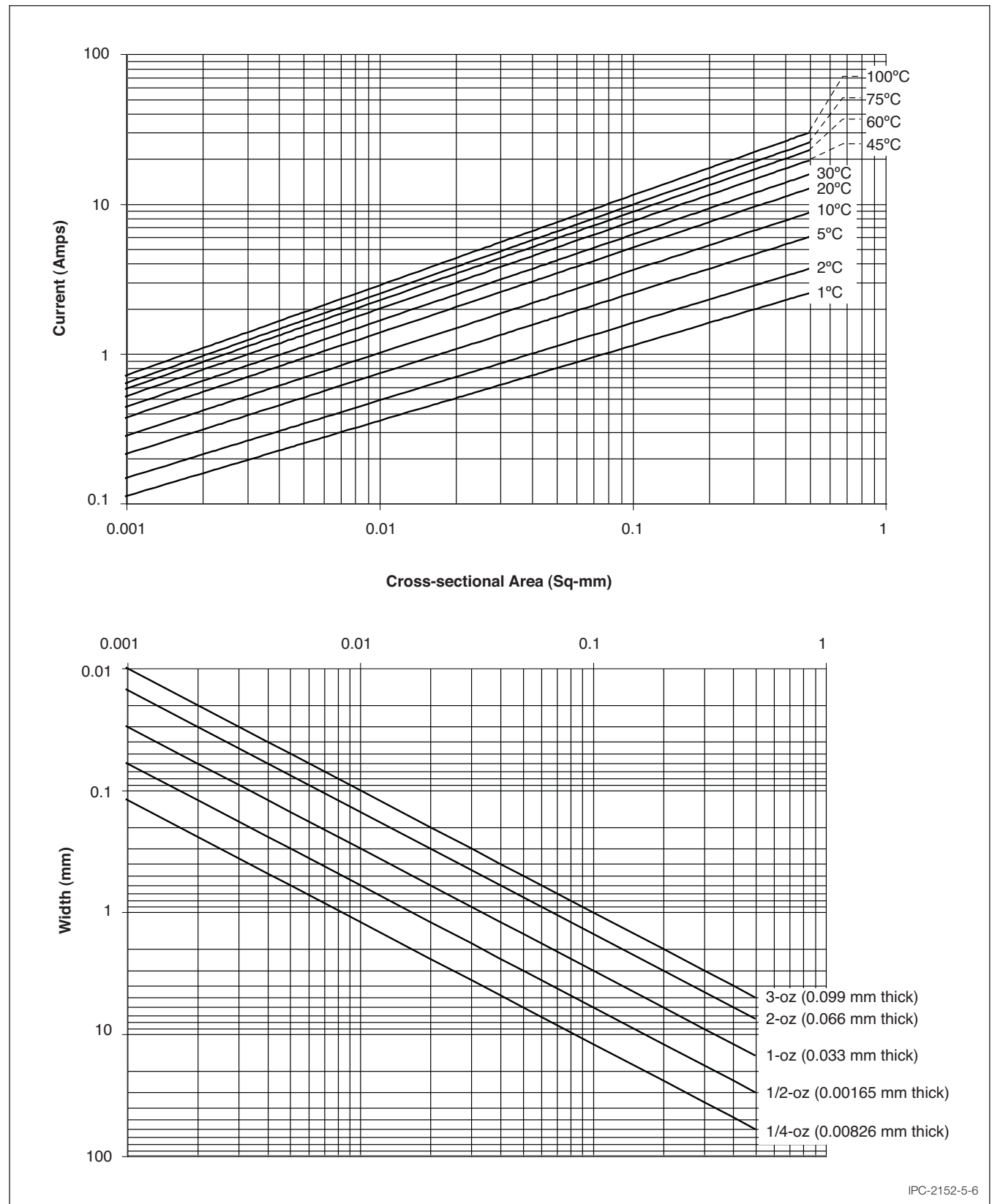


Figure 5-6 Internal and External Conductors (Still Air) (0.001 - 0.5 Sq-mm)

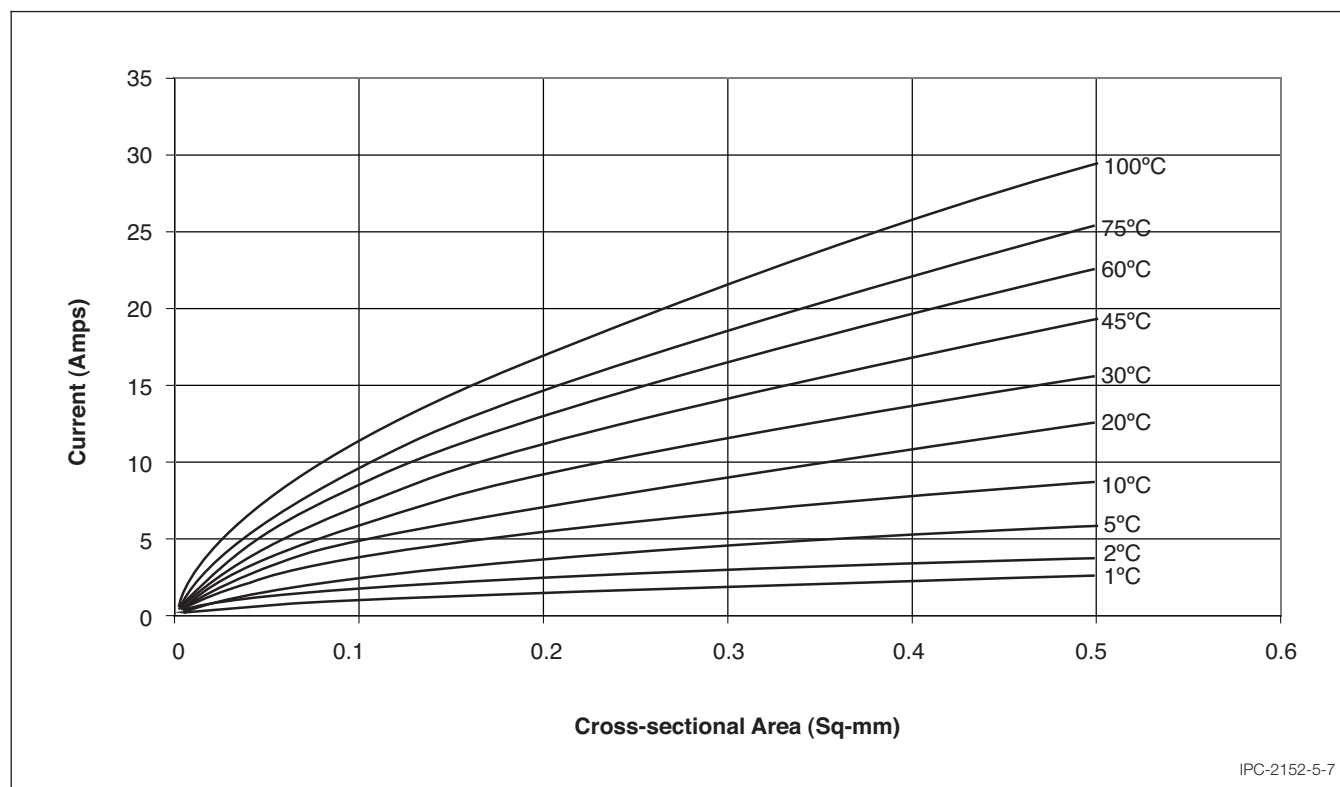


Figure 5-7 Internal and External Conductors (Still Air) (0.001 - 0.5 Sq-mm)

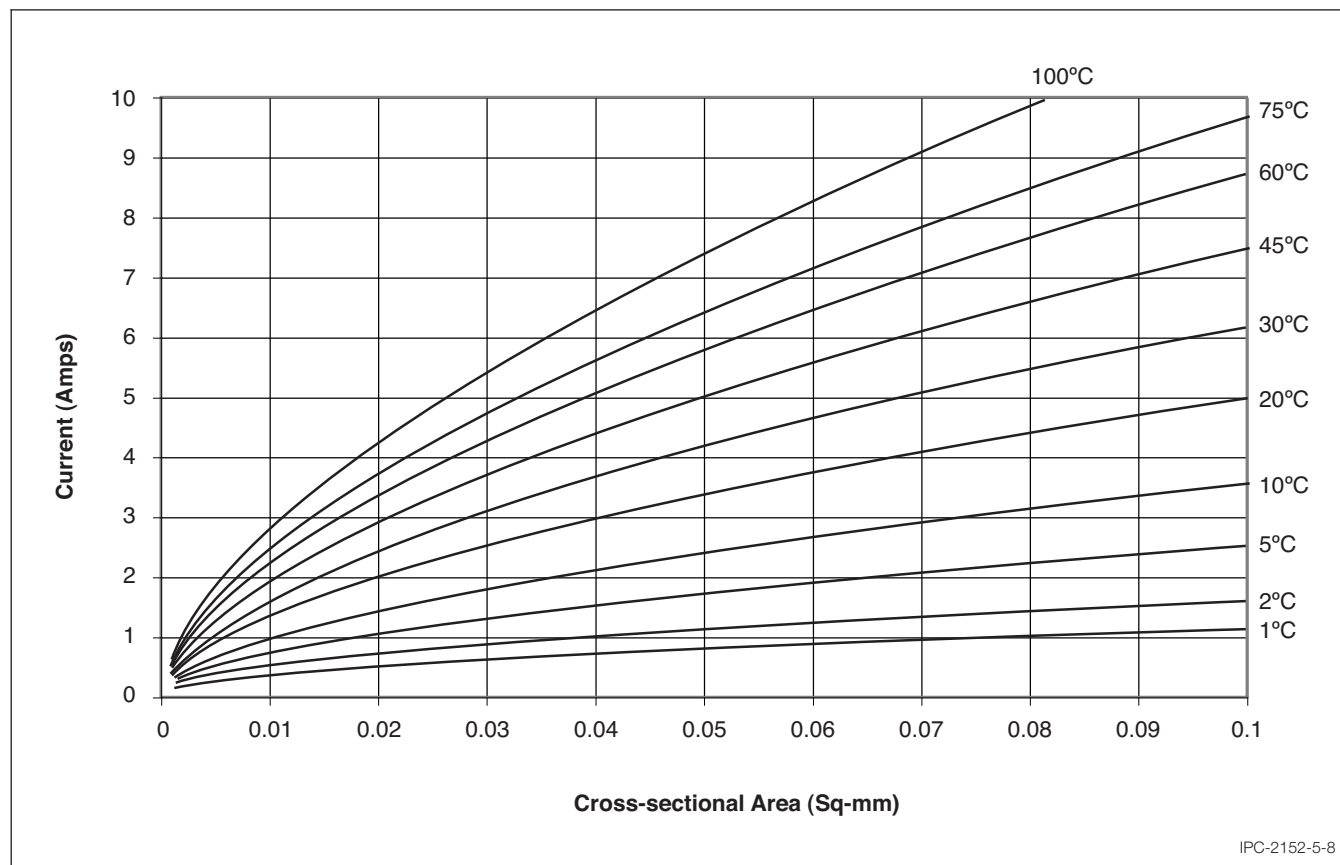


Figure 5-8 Internal and External Conductors (Still Air) (0.001 - 0.1 Sq-mm)

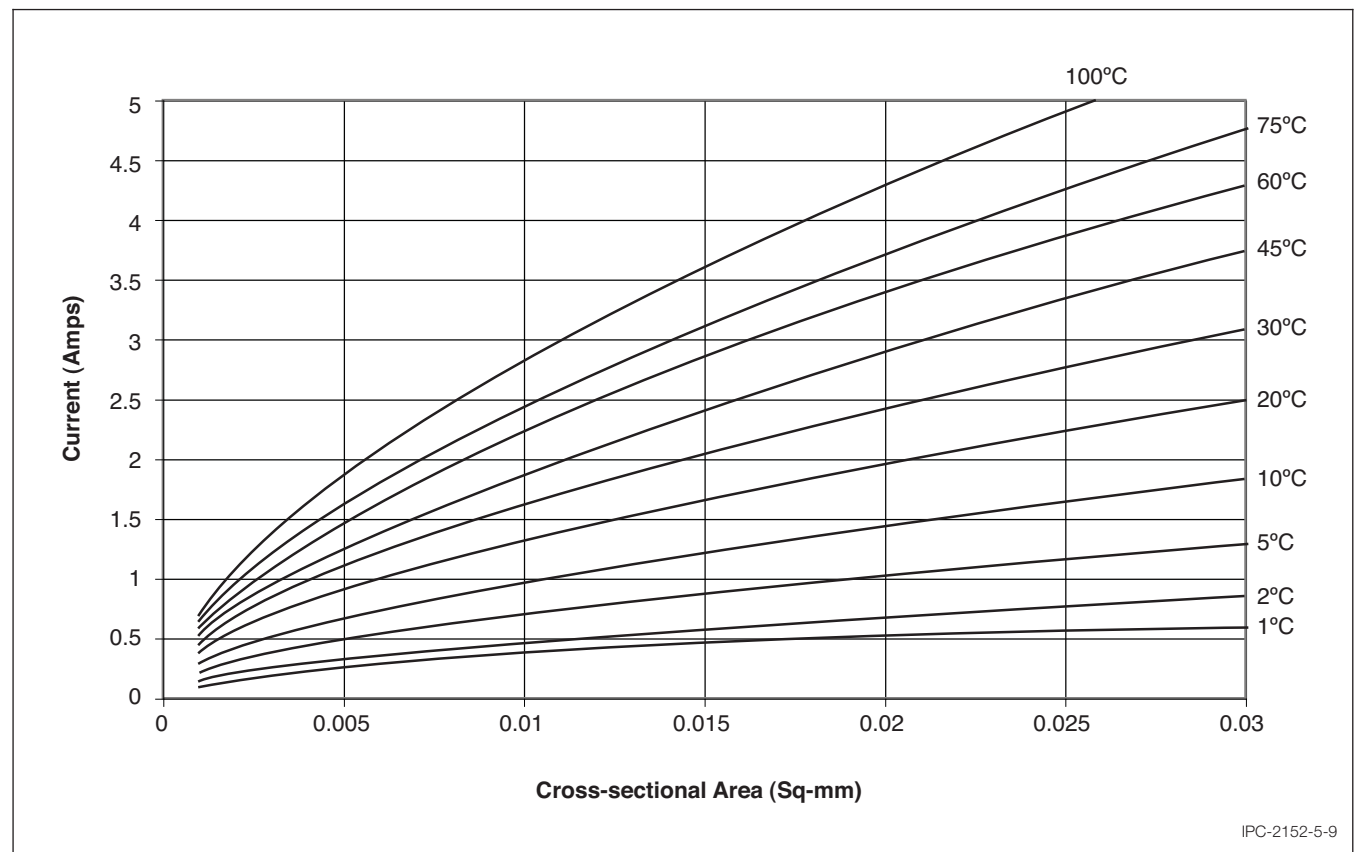


Figure 5-9 Internal and External Conductors (Still Air) (0.001 - 0.03 Sq-mm)

5.2 Conductor Sizing Charts for Vacuum/Space Environments The following charts are for vacuum or space environments. They can also be considered as a conservative estimate for high altitude requirements.

5.2.1 Vacuum/Space Environment Charts in Imperial (Inch) Units Figure 5-10 through Figure 5-13 represent charts for internal and external conductors in vacuum environments in imperial (inch) units.

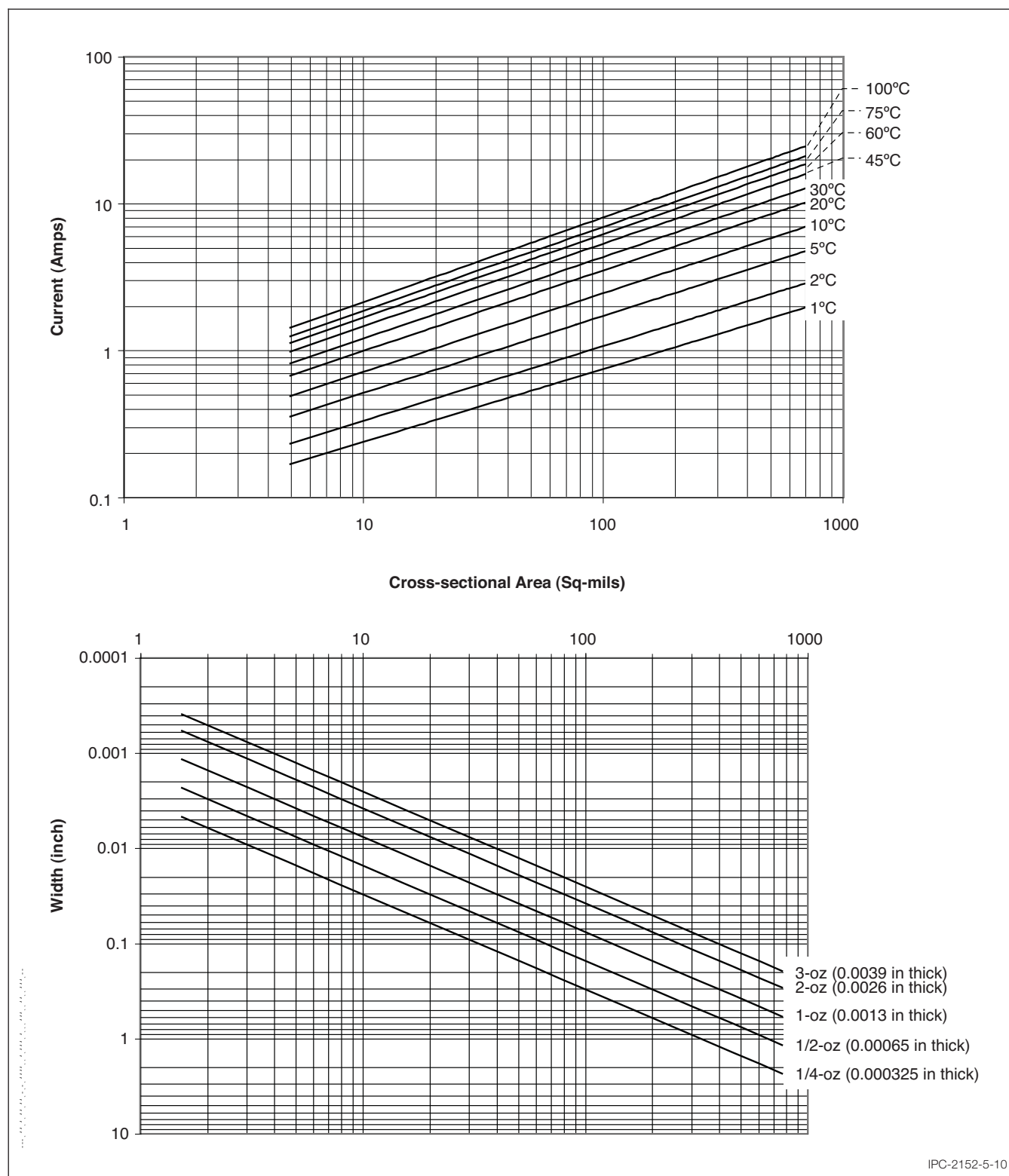


Figure 5-10 Internal and External Conductors (Vacuum) (5 - 700 Sq-mils)

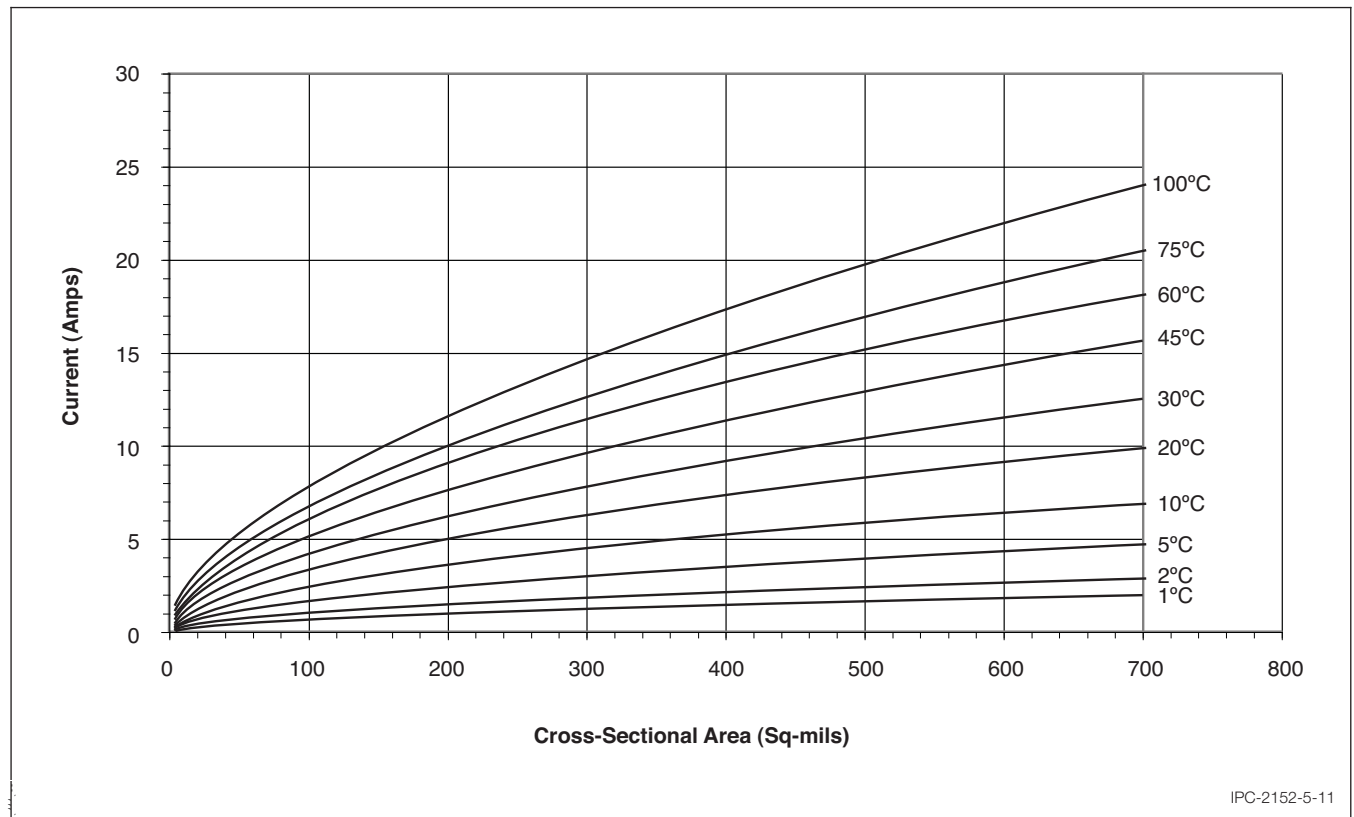


Figure 5-11 Internal and External Conductors (Vacuum) (5 - 700 Sq-mils)

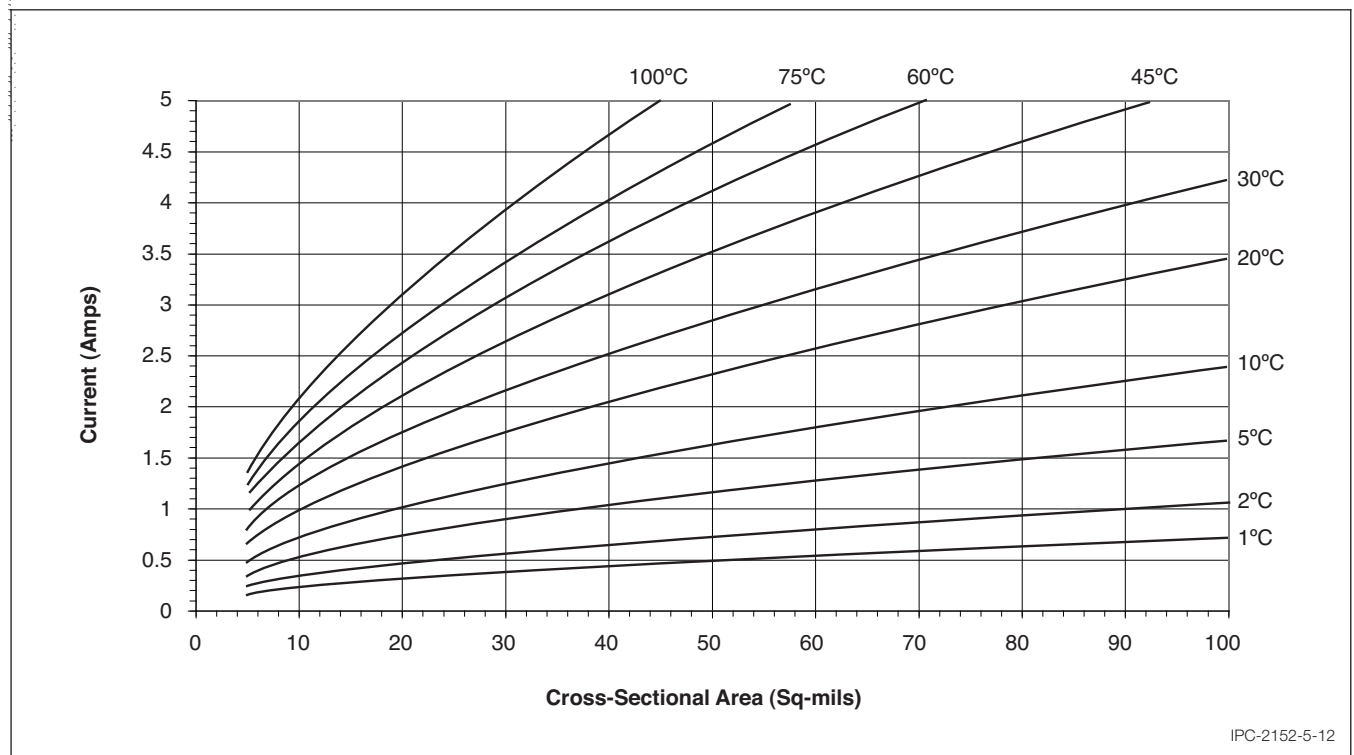


Figure 5-12 Internal and External Conductors (Vacuum) (5 - 100 Sq-mils)

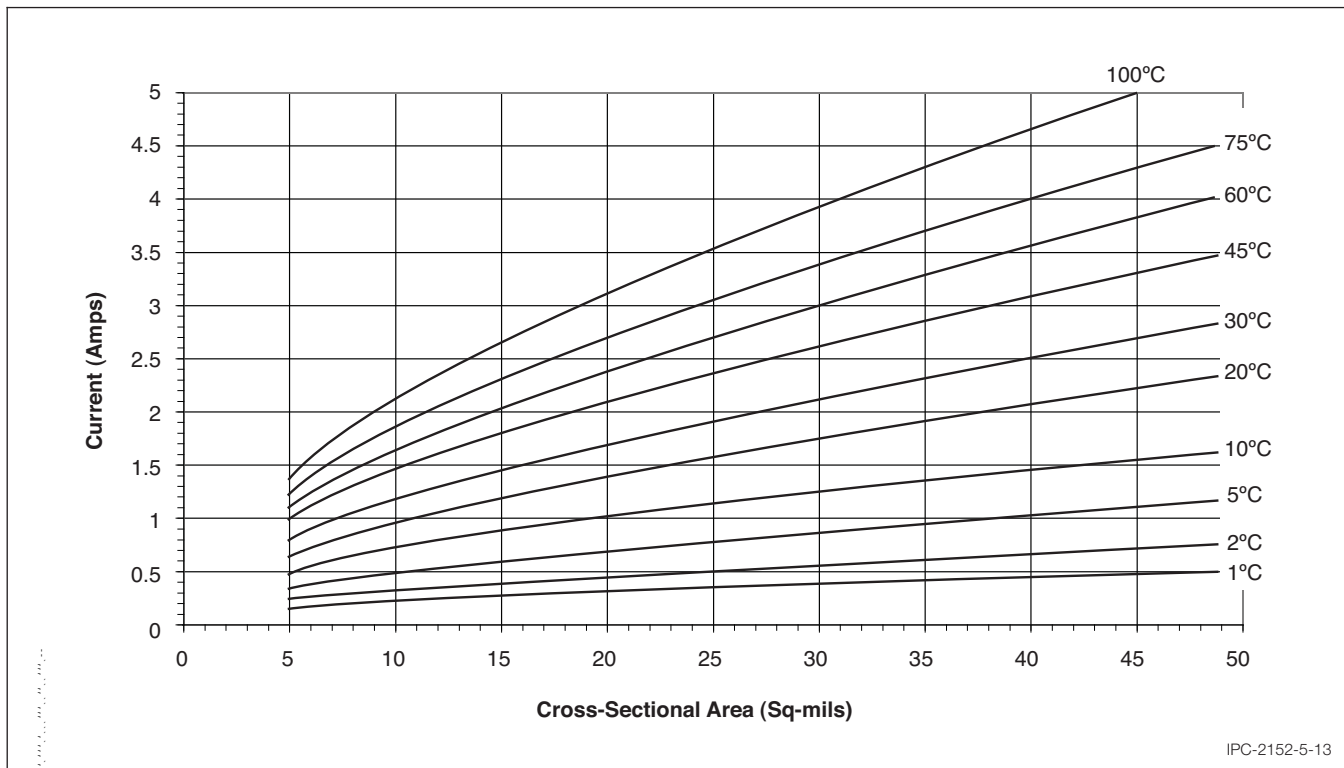


Figure 5-13 Internal and External Conductors (Vacuum) (5 - 50 Sq-mils)

5.2.2 Vacuum/Space Environment Charts in SI (Metric) Units Figure 5-14 through Figure 5-17 represent charts for internal and external conductors in vacuum environments in SI (metric) units.

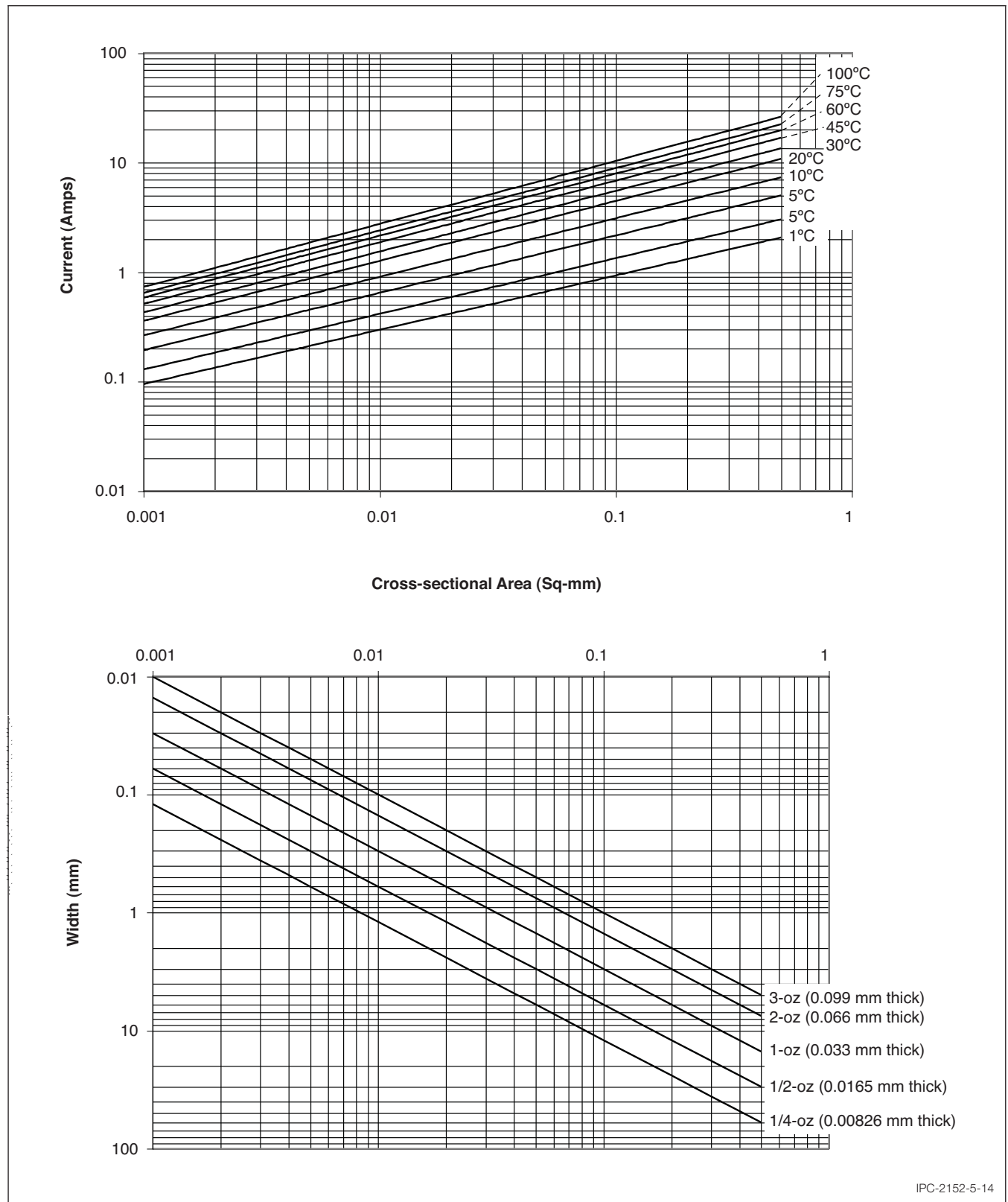


Figure 5-14 Internal and External Conductors (Vacuum) (0.001 - 0.5 Sq-mm)

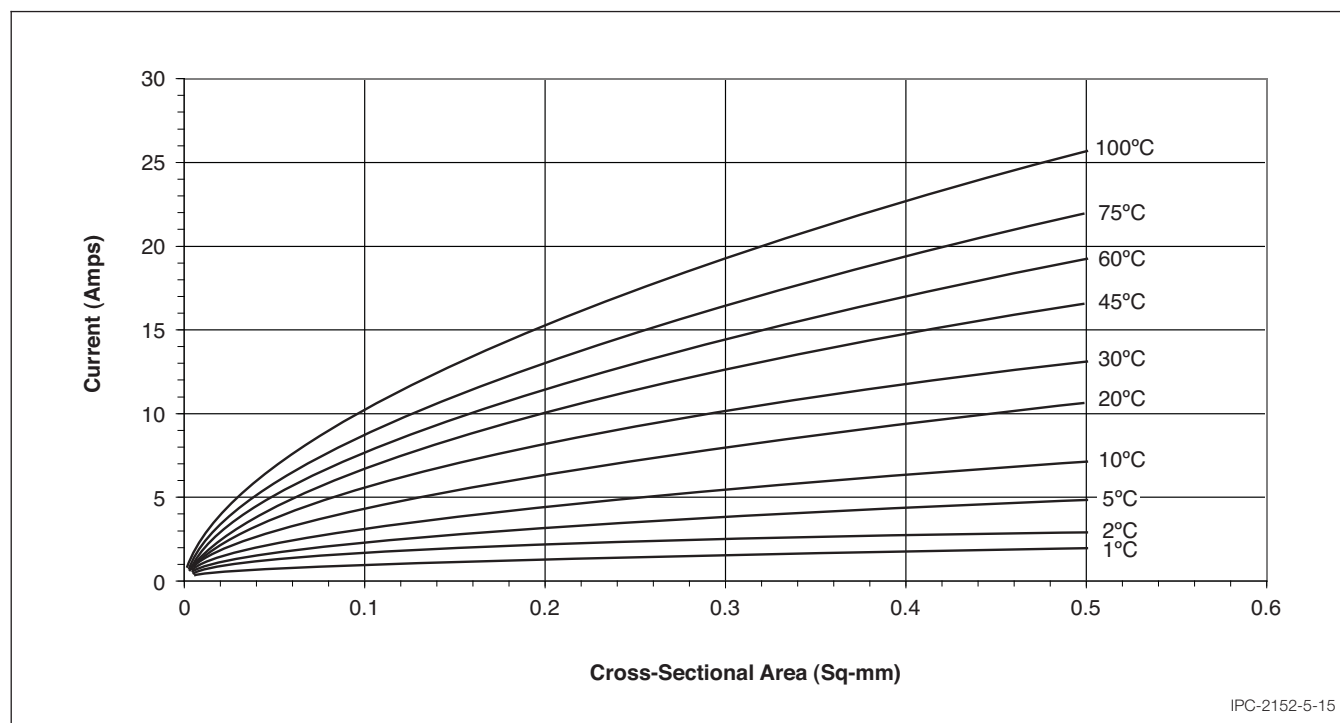


Figure 5-15 Internal and External Conductors (Vacuum) (0.001 - 0.5 Sq-mm)

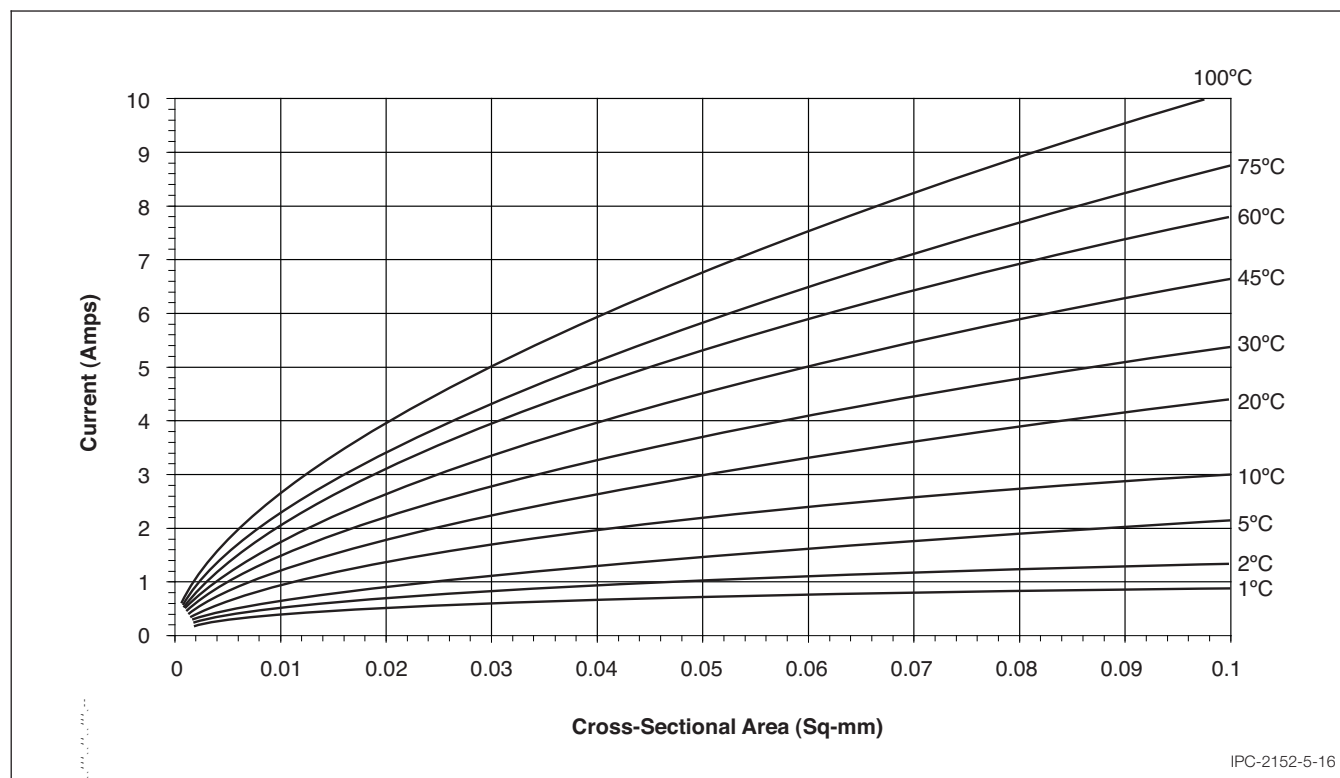


Figure 5-16 Internal and External Conductors (Vacuum) (0.001 - 0.1 Sq-mm)

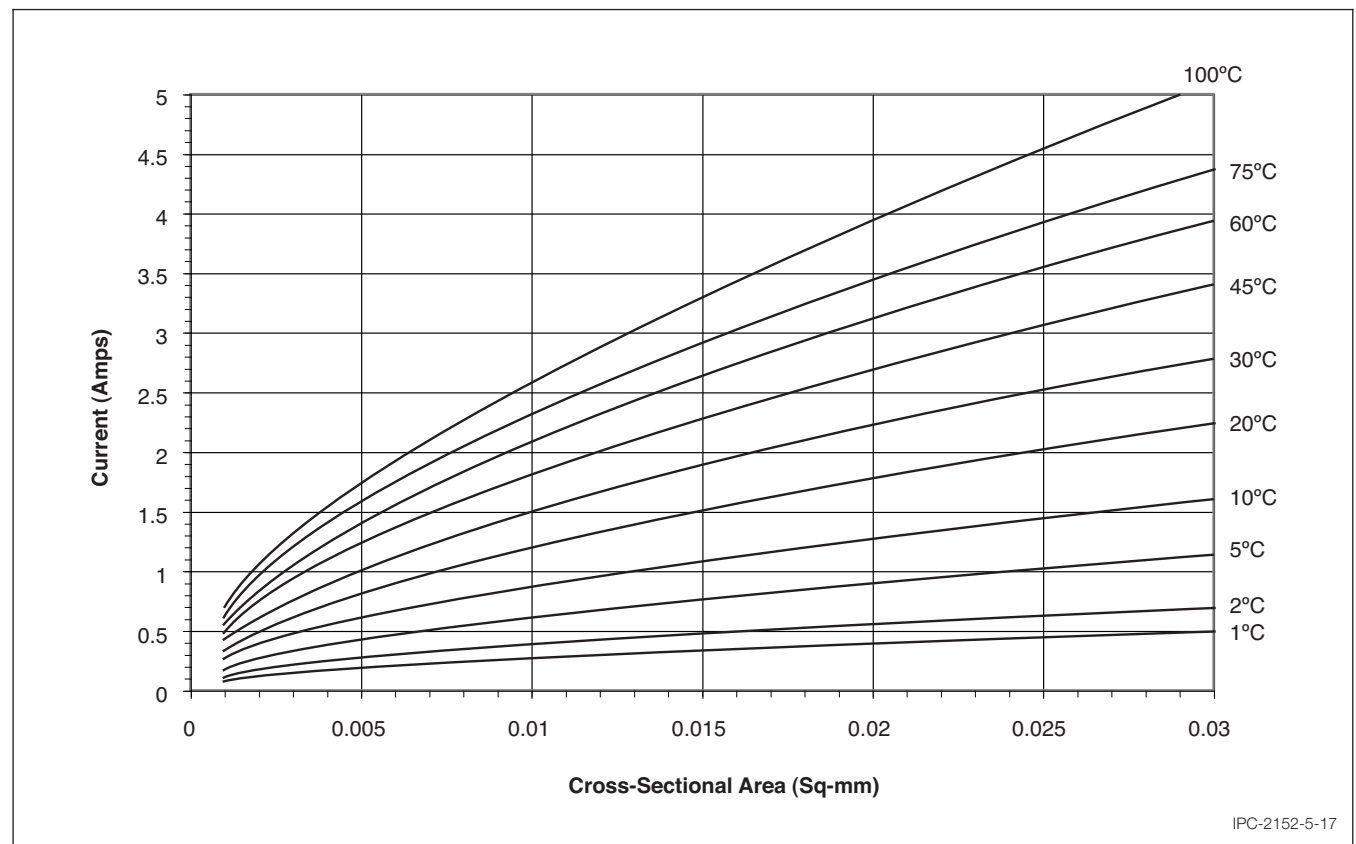


Figure 5-17 Internal and External Conductors (Vacuum) (0.001 - 0.03 Sq-mm)

APPENDIX A

A.1 INTRODUCTION

This appendix is included as a resource for topics concerning conductor temperature rise and determining current carrying capacity in printed board (PB) conductors.

PBs can be extremely different from one design to another. They can vary from a double-sided PB the size of a postage stamp to a forty layer PB that is two feet wide, four feet long and a half-inch thick. The environment in which the PB must operate is also a consideration, whether it is used on Earth, at sea-level or 18,288 m [60,000 ft], immersed in a fluid, operating in space (vacuum), or on some other planet.

With such a broad range of PB construction, materials, and operating environments, a single conductor-sizing chart cannot be expected to describe the temperature rise of a conductor as a function of current for all PB designs. Fine line and space, heavy copper, single-layer PBs and multilayer PBs all constitute different configurations in which conductors with the same cross-sectional area vary from 10 to 100 °C or more for the same amount of applied current.

If the designer is coming to this appendix as a means of reducing conductor size and/or determining temperature margin, then a new set of criteria needs to be considered. The criteria are PB thickness, copper thickness, number of copper plane layers and the distance from the conductor to each adjacent copper plane layer.

The charts in IPC-2152, with the exception of Figure 5-1 (which is duplicated in this Appendix as Figure A-1), are developed from 1.79 mm [0.070 in] thick, polyimide PB test vehicles. This appendix discusses how PB thickness, copper thickness vs. cross-sectional area, copper plane layers, and the distance from a conductor to a copper plane layer affect the temperature rise of a PB conductor.

Information in this appendix was developed from current carrying capacity testing using polyimide and FR-4 PB test vehicles with no internal copper planes. Test vehicles and testing were performed following IPC-TM-650, Method 2.5.4.1. Data from 1.79 mm [0.070 in] thick polyimide PB test vehicles are presented in the form of charts. Although data was also collected for FR-4 boards with thicknesses of 0.965 mm [0.038 in] and 1.50 mm [0.059 in], only the polyimide data is presented. The FR-4 data sets are used for comparison and to discuss the effect of the PB thickness and material thermal conductivity with respect to the charts in IPC-2152.

A.2 DERATING

Conductors that are sized using IPC-2152 have no specific derating applied to them. In most cases, conductors will operate at a temperature rise less than estimated using the charts in this document. In the general case of a PB that has one or more copper planes in the PB, the conductors will have a lower temperature rise than estimated using the conductor sizing charts. Conductor temperature rise margins based on the presence of copper plane layers in a PB design can be estimated using guidelines in A.4.6.

Internal and external conductors operate very close to the same temperature rise for the same applied current and cross-sectional area. Conductors in a vacuum environment operate at higher temperatures than in air for the same size conductor and applied current.

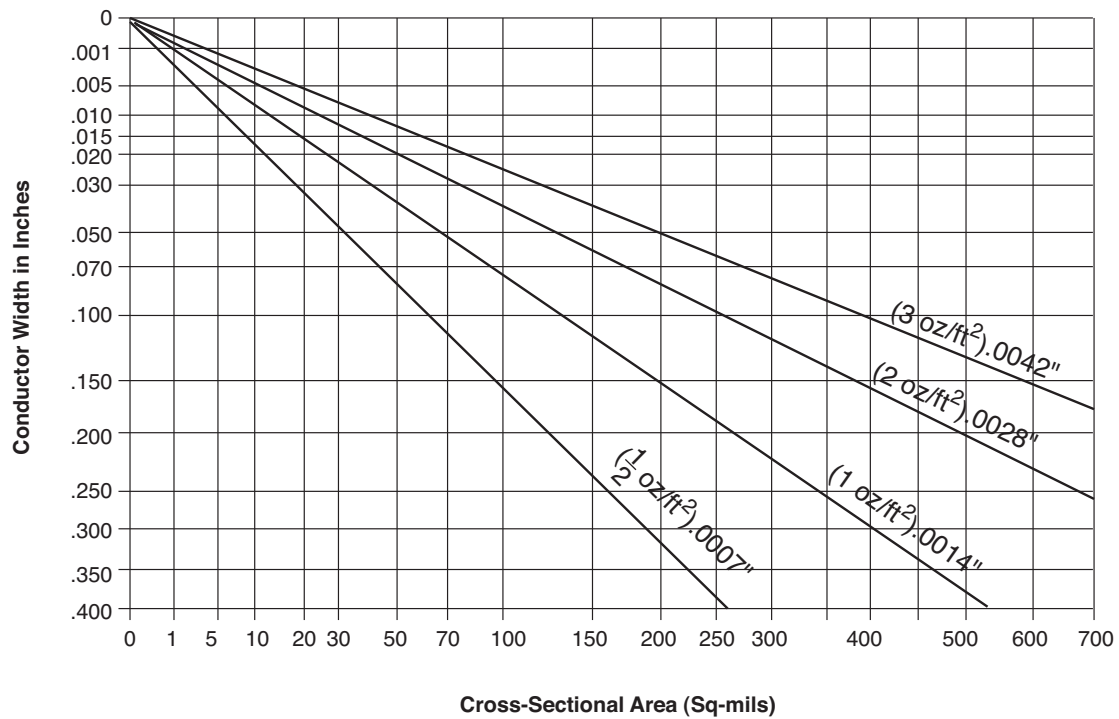
A.3 SELECTING A CHART

A chart is selected by knowing the desired conductor thickness and the environment in which it will operate, such as in air or vacuum.

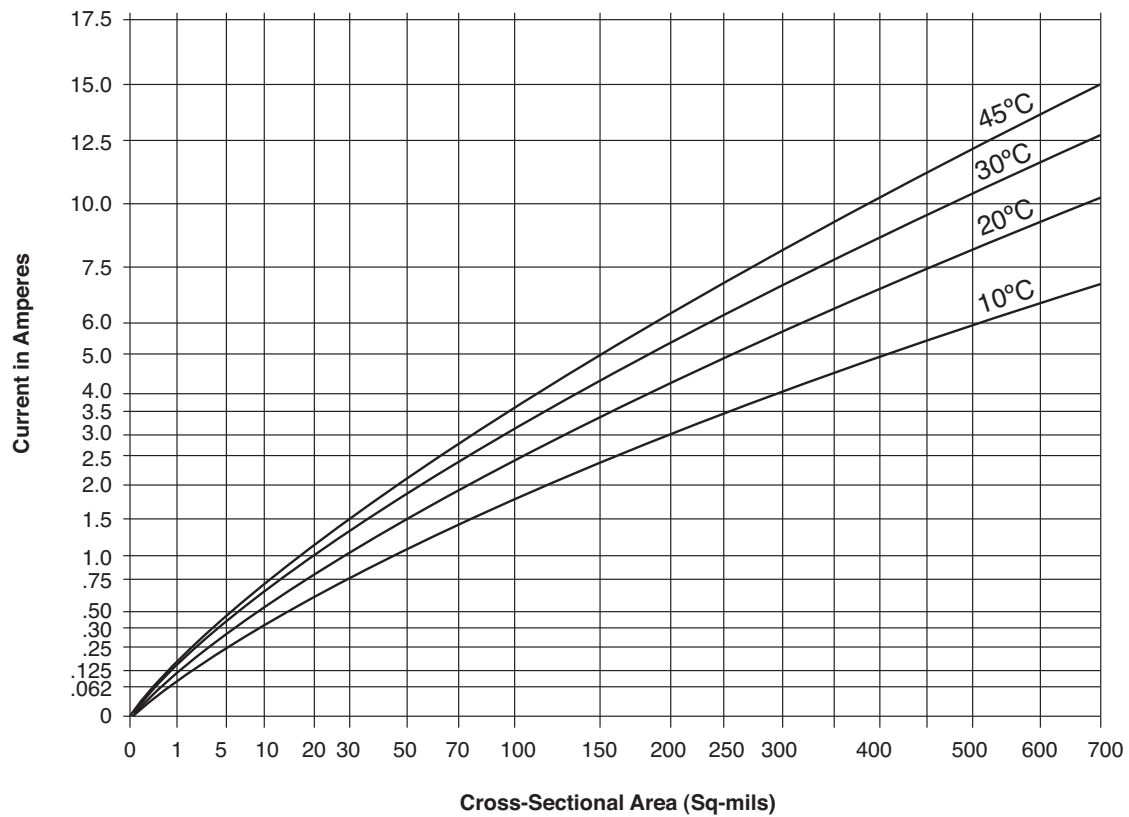
Considerations before selecting a chart include:

- PB Material:** If the PB material is not polyimide or FR-4, and if the material has a lower thermal conductivity than the values listed in Table A-3, it is recommended to only use Figure A-1 for sizing conductors.
- PB Thickness:** If the PB thickness is less than 1.79 mm [0.070 in], see A.4.2.
- Conductor Thickness:** Increasing the width of a conductor by using a thinner copper layer for a desired conductor cross-sectional area will lower the temperature rise of a conductor. (See the charts for the differences.)

Figure A-1 is the most conservative of all conductor-sizing charts, taking into consideration both internal and external conductors, the PB material, board thickness, and environmental conditions such as air or vacuum. Presented in A.7.1 is a full discussion of the chart in Figure A-1. Conservative, in this case, is when the actual temperature rise of a conductor is lower than that estimated by the chart.



Conductor width to cross-section relationship



IPC-2152-a-1

Figure A-1 External and Internal Conductors (This figure is a duplicate of Figure 5-1 in IPC-2152)



Figure A-15 through Figure A-89 represent test data collected using test vehicles made from polyimide PB material. The charts are organized with respect to copper thickness, external conductors (air) in imperial (inch) units, external conductors (air) in SI (metric) units, internal conductors (air) in imperial (inch) units, internal conductors (air) in SI (metric) units and then charts following the same outline for vacuum environments.

A.3.1 Conductor Temperature Rise The conductor temperature rise derived from a chart represents the increase in the conductor temperature above the local PB temperature surrounding the conductor. Knowing the continuous current that is applied to a specific size conductor and using the most appropriate chart, an estimate of the conductor temperature rise can be made. The cross-sectional area is defined by the width and thickness of the conductor.

The temperature rise as mentioned above is the increase in conductor temperature above the local PB temperature when current is applied. For example, if the PB operates at 85 °C and the conductor is designed for a 10 °C rise, then the conductor will be 95 °C. A 10 °C rise is a common temperature rise for a design. The temperature rise should always be minimized. Increasing the size of a conductor will lower the temperature rise, lower the power being dissipated in the PB, lower the voltage drop across the conductor, decrease component temperatures and improve the reliability of the product. It is important to always consider the component temperature for its worst-case environment to determine the allowable conductor temperature rise.

The designer must know the PB temperature during the worst case operating conditions. The PB temperature must take into consideration the power dissipation from the components, conductors, connectors, mounting configuration and environment that it must operate.

A.3.2 How to Use the Charts Conductor sizing charts require knowing two of three variables: current, conductor temperature rise, or conductor cross-sectional area. Knowing any two of the three variables will allow the other to be determined.

A.3.2.1 Chart Basics: Known Current When the current and the desired temperature rise are known, then the conductor width can be calculated for various conductor thicknesses.

Example 1: What is the recommended size conductor for a 10 °C rise when 1 Amp is applied to it?

Starting with the upper chart in Figure A-2, follow the line going across from 1 Amp to the curve labeled 10 °C. The 10 °C curve represents the temperature rise that will occur for a specific size conductor at a specific current level. Next, follow the line going down from the 10 °C curve and look at where it intersects the axis labeled “Cross-Sectional Area Sq-mils”. The cross section is the cross-sectional area of the conductor. The final step is to determine the conductor width.

The lower chart in Figure A-2 is used to determine the conductor width for various copper thicknesses. For the same cross-sectional area, the width will be smaller for thick copper and wider for thinner copper. Continuing with the example, follow the vertical line down from 50 sq-mils into the lower chart to the line labeled “1 oz. (0.0013” thick). Following the line across to the axis labeled “Width (inch)” it shows the conductor should be approximately 0.040 in. wide for a copper conductor that is 0.0013 in. thick. If 3 oz. copper was selected, the conductor width would be approximately 0.015 in wide, rather than 0.040 in wide for 1 oz. copper.

A.3.3 Parallel Conductors Parallel conductors refer to conductors on the same layer as shown in Figure A-3, as well as conductors on adjacent layers. The concept of parallel conductors and how to calculate the cross-sectional area of a group of parallel conductors is critical to properly sizing PB conductors. The method for sizing parallel conductors from the design guidelines is described below.

For groups of closely spaced parallel conductors, the temperature rise may be found by using an equivalent cross-section and an equivalent current. (Closely spaced is on the order of 25.4 mm [1.0 in] spacing and less.) The equivalent cross-section is equal to the sum of the cross-section of the parallel conductors, and the equivalent current is the sum of the current in each of the parallel conductors.

Example 2: Determine the maximum current in a 0.03 mm [0.0011 in] wide conductor, ¼-oz. copper (0.00035 in thick), with a maximum temperature rise of 10 °C; if there are 16 conductors in parallel.

- Cross-sectional area of one conductor = $0.00035 \times 0.0011 \text{ in.} = 3.85 \text{ E-}07 \text{ in}^2 = 0.385 \text{ sq-mils.}$
- Cross-sectional area of 16 conductors = $3.85 \times \text{E-}07 \text{ in}^2 \times 16 = 6.2 \text{ sq-mils.}$
- Find the current for the total cross-sectional area, 6.2 sq-mils, and a 10 °C rise using the charts in Figure A-35 through Figure A-38, which results in 0.7 Amps.

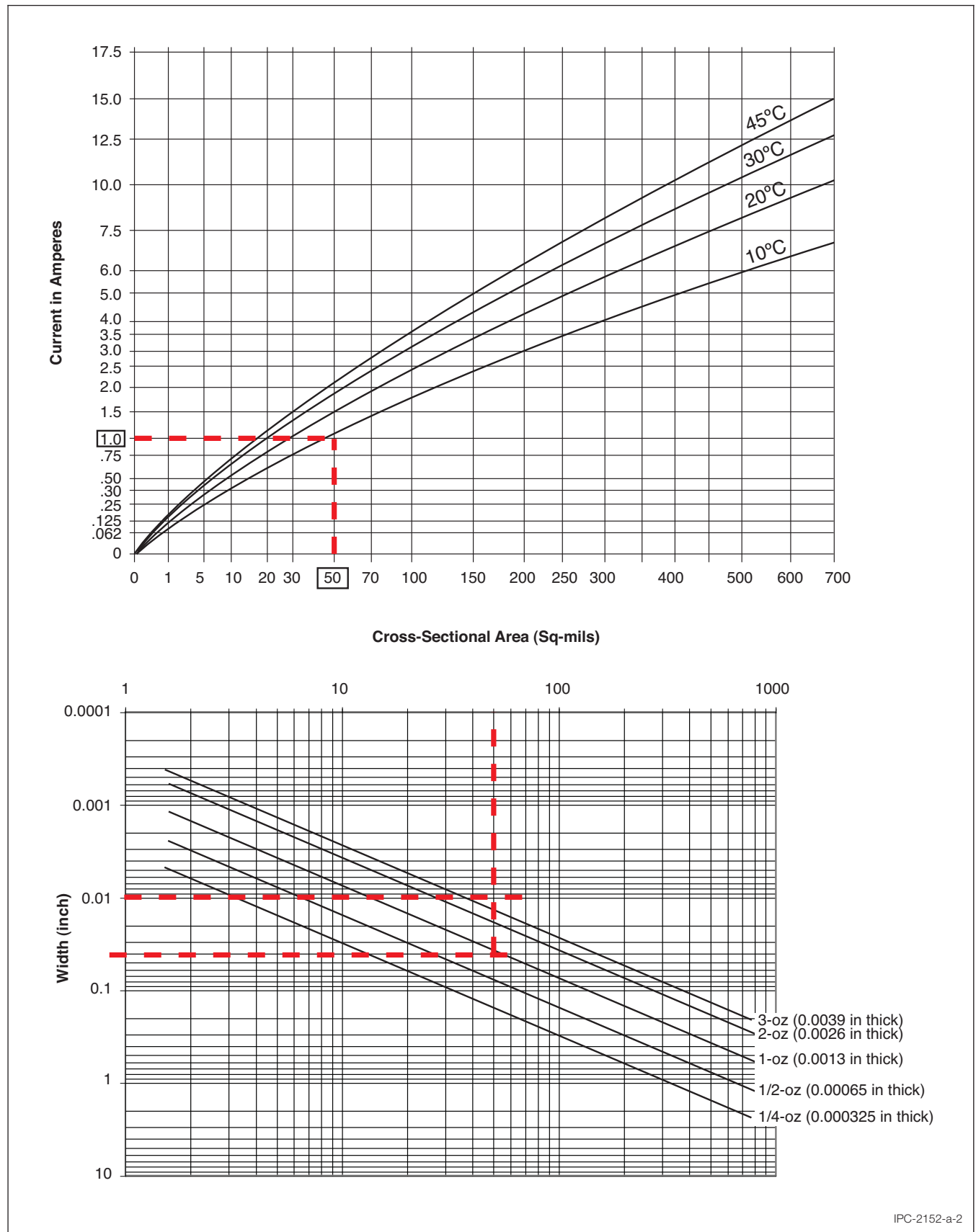


Figure A-2 External and Internal Conductor Sizing Chart

- d) Divide the current by 16 conductors, $0.7/16 = 0.0438$ Amps.
- e) Round down = 0.04 Amps per conductor.
- f) For boards that are less than [0.070 in] thick, the temperature rise will be higher. A.4.2 discusses PB thickness and conductor temperature rise.
- g) If copper planes are present in the PB, then the temperature rise will be lower. It is recommended to use copper planes for design margin and not for actual sizing of conductors. Methods for estimating the temperature effect of copper planes are discussed in A.4.6.

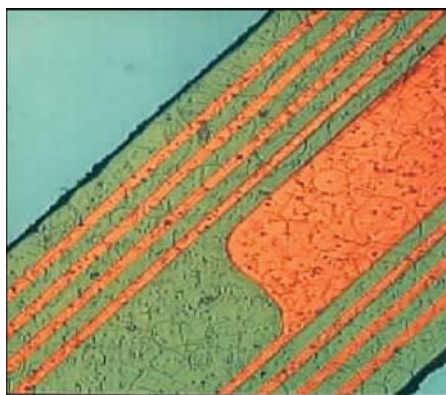


Figure A-3 Parallel Conductors

Conductor Spacing: Fine line conductors and spacing as shown in Figure A-3 are easily distinguished as parallel conductors. In other cases, the temperature gradient around the conductor can determine when the parallel conductor rule should be used. A general rule is that conductors within 25.4 mm [1.0 in] spacing should be considered parallel. The rule is based on a 12.7 mm [0.5 in] gradient on the side of each conductor. That is the significant area of temperature change. See Figure A-4 and Figure A-5. The temperature gradient will extend to all sides of the conductor. As conductors are spaced closely with each other their gradients overlap, which causes each of the conductors to increase in temperature. The temperature gradients in the following figures are representative for polyimide and FR-4 PBs with no copper planes. To estimate the change in conductor temperature rise when copper planes are present, see A.4.6.

The temperature gradient around a single conductor is illustrated in Figure A-4 and Figure A-5. Figure A-4 represents a 0.254 mm [0.010 in] wide internal conductor, with a 10 °C rise, in a 1.79 mm [0.070 in] thick polyimide PB. The numbers on the left side of the illustration show the distance from conductor at 35 °C to the PB temperature at the distances shown. This illustrates the temperature gradient in a PB with no copper planes. The conductor in Figure A-4 is internal and too small to see the 35 °C temperatures. The conductor itself is at 35 °C.

Example 3: Figure A-5 represents an internal, 1-oz., 4.06 mm [0.160 in] wide conductor, in a polyimide PB that is 1.79 mm [0.070 in] thick. The PB is in still air and represents the test configuration defined in IPC-TM-650, Method 2.5.4.1. The conductor is designed for a 10 °C rise. The conductor is large enough to show a small temperature difference between the conductor at 35 °C and external PB temperature directly above the conductor, which is less than 1 °C cooler in a still air environment.

When comparing the conductor temperature gradient in Figure A-4 and Figure A-5, the purpose of these two figures is to show that, at 0.127 mm [0.5 in], there is a small temperature rise that will begin to overlap with another conductor that is at the same temperature rise.

Figure A-6 shows two parallel 2.03 mm [0.080 in] conductors, separated by 2.54 mm [0.100 in], each with half the current as a single 4.06 mm [0.160 in] conductor designed for a 10 °C rise. The two parallel conductors each have a 9.4 °C rise.

Figure A-7 shows the same two 2.03 mm [0.080 in] wide conductors each designed for a 10 °C rise and not following the parallel conductor sizing rules. In this case, a 17.35 °C temperature rise results from not following the parallel conductor sizing rules.

Figure A-8 and Figure A-9 show how the conductor temperature rise drops as separation distance between the conductors increases. The conductors in Figure A-8 and Figure A-9 are designed following the parallel conductor-sizing rule. The conductors in Figure A-10 show the temperature rise when the parallel conductor rule is not used with 25.4 mm [1.0 in] spacing.

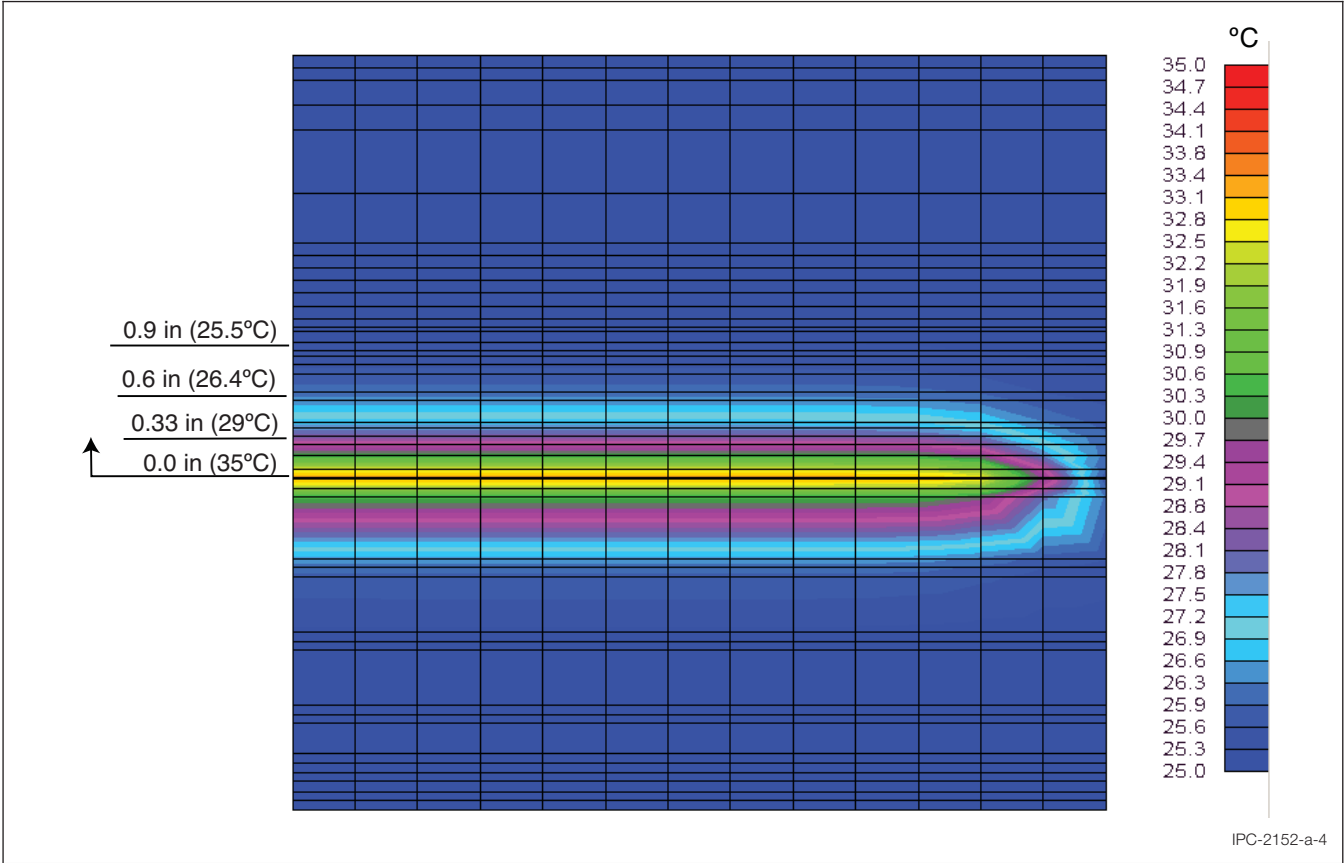


Figure A-4 [0.010 in] wide (1-oz.) Conductor at 10 °C Temperature Gradient

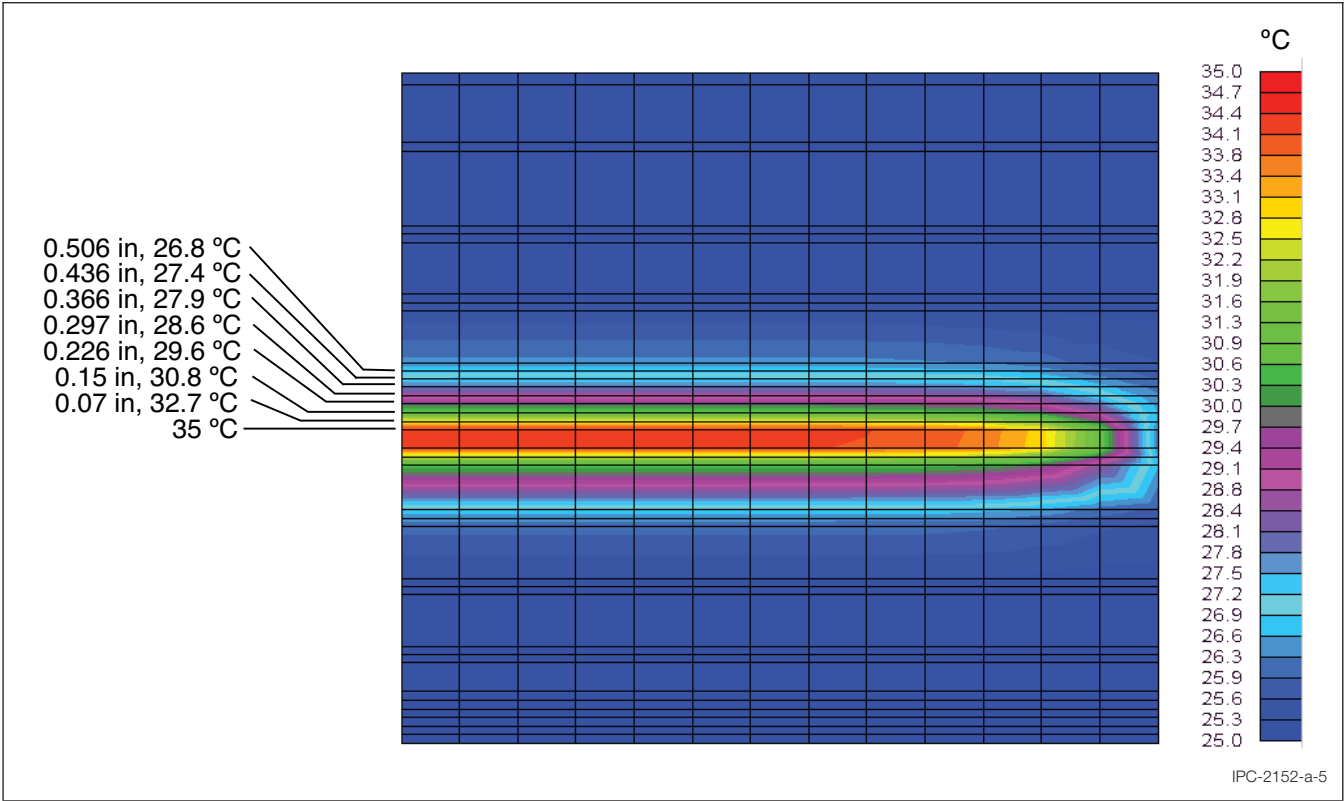


Figure A-5 4.06 mm [0.160 in] Single Conductor