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# **Thermal Management Calculator Discussion**

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#### Thermal Manangement Calculator

This "Calculator" is for sizing electrical conductors in printed circuit boards. The **Thermal Management Software** is a database of current carrying capacity data. Data from this software database were used to create "*Standard for Determining Conductor Current-Carrying Capacity In Printed Board Design*", IPC 2152. This design tool has more information than was published in the standard. It is for determining the size of electrical conductors based on the temperature rise of conductors as a function of PCB physical parameters and current.

As some people know and others are learning, the charts in IPC-2221 goes back to work performed by the National Bureau of Standards in 1955 and published in 1956. Their work only addressed external conductors. Those conductors were on Phenolic and Epoxy boards. In addition, their results were all compiled together to create a chart that was labeled "tentative". Their test results were a mix of variables that effect trace temperature, such as board thickness, board material, trace thickness and some of the test boards had copper planes on the back of them. All of these variables influence the temperature rise of the trace, some more significantly than others, which makes it difficult to ascertain the actual temperature change of a trace in various board configurations. That was for the external traces. The internal trace charts were not based on test data, they were simply based on half the current from the external trace chart. This has caused problems throughout the electronics design community due to increasing currents, high-density electronics and design standards that are not well understood.

Now with a fresh start, all of the variables are separated, so that design decisions can be made with a better understanding of conductor heating. The **Thermal Management Software** is a collection of years of research. The database contains test results that have been validated by a U.S. Air Force Independent Research group and a Navy test lab. The test data covers 1 and 2oz internal and 2oz external traces for FR4 and ½ oz, 1, 2, 3 oz internal and 2, 3 oz external traces for polyimide in Air and Vacuum.

Additional information is also included that shows the influence of copper planes on heat spreading and lowering trace temperatures. The software has the capability of importing new trace charts. A process of creating technology specific design charts is well defined.

As new charts are created they can be imported through an "Ingest Tool". The interface is simple and only requires data input through a comma separated variable format.

Thermalman Ingest Tool	?	×
		~
Source Filename (EXCEL .csv file)		
Destination Path for output file		
Enter output filename		
Close Ing	est	

Figures 1-9 shows the initial graphical user interface for the calculator followed by other attributes.

Configura	ation 🚺	Aike_fav	v	-			💽 Inte	emal 🔘	External					Type:	Trace	e 💌
Thicknes	ss Table	PC Minir	mum External	-			Charts	IPC		•				Conduct	or: 0.5oz	Coppe
Calculato Sizing ross Sec	r tional Area	(mil^2)	12.000000	Hold				1ozAirIntFR4 1ozAirIntFR4 2ozAirIntFR4	4038A04 4059 4038A02	▲ ctr	rical	h (in)	1.00	00	Hold	
onducto	r Thickness	(in)	0.001200					2ozAirIntFR4 0.5ozAirIntP	4059A05 olv07	vier	nt Temp ("	C)	25.00	0000	305.309	65
Conduc	ctor Width *	(in)	0.010					1ozAirIntPol	y07	_	anon (Ohm	ا م	nitial	State (0)	Final Sta	te (F)
Cu	urrent * (A)		1.736					3ozAirIntPol	y07	age	e Drop (V)	" I	0.10	09	0.13080	
Temper	ature Rise *	(°C)	280.30965				2	0.5ozVacInt	Poly07	Former	Disation	- 000	0.18	19	0.394	
							/			onei	Dissipation	u (aa)				
click to s	solve param	eter.	Reset				/			Power	Density (V	V/in^2)	18.9	42	39.404	
click to s Results	solve param	eter.	Reset			/	/			Power	Density (V	V/in^2)	18.9	42	39.404	
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click to s Results Ad Type	solve param	eter. Modif	Reset	)elete Thickn	ess (in) V	Width (n)	Length (in)	Area (mil^2)	Current (/	Power	Density (V	V/in <sup>2</sup> )	18.9 (°C)	42 Columns Resist F (Ol	39.404 Pr hm) Vdro	int pF(V)
click to s Results – Ad Type Trace	Id Location	Modif Chart 5x5Airl	Fr41ozp005	Delete	ess (in) V	Width (n)	Length (in) 1.000	Area (mil^2) 12.000000	Current (/ 1.736	Power A) De 10.0	elta T (°C)	V/in^2)	18.9 (°C)	42 Columns Resist F (O 0.0613270	39.404 Pr hm) Vdro 0.10	int p F (V) 06
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Ad Type Trace Trace Trace Trace Trace Trace Trace	ld Location Internal Internal Internal	Modif Chart 5x5Airl 1ozAirl 3ozVao IPC	Fr41ozp005 IntPoly07 cIntPoly07	Delete Thickn 0.00120 0.00120 0.00120 0.00120	ess (in) V 00 ( 00 ( 00 ( 00 (	Width (n) 0.010 0.011 0.010 0.010	Length (in) 1.000 1.000 1.000 1.000	Area (mil^2) 12.000000 12.000000 12.000000 12.000000	Current (/ 1.736 1.736 1.736 1.736	A) De 10.1 31. 54. 280	elta T ("C) 00000 13496 19120 0.30965	Temp F 35.0000 56.1349 79.1912 305.309	18.9 (°C) 0 65	42 Columns Resist F (Ol 0.0613279 0.0661374 0.0713841 0.1308047	39.404 Pr hm) Vdro 0.10 0.11 0.12	int p F (V) 06 15 24 27
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Click to s Results Ad Type Trace Trace Trace Trace	Id Location Internal Internal Internal Internal	Modif Chart 5x5Airt 1ozAirt 3ozVac IPC	Fr41ozp005 IntPoly07 cIntPoly07	Delete Thickno 0.00120 0.00120 0.00120 0.00120	ess (in) V 00 ( 00 ( 00 ( 00 (	Width (n) 0.010 0.010 0.010 0.010 0.010	Length (in) 1.000 1.000 1.000 1.000	Area (mil^2) 12.00000 12.00000 12.00000 12.00000	Current (/ 1.736 1.736 1.736 1.736	A) De 10. 31. 54. 280	elta T ("C) 00000 13496 19120 0.30965	Temp F 35.0000 56.1349 79.1912( 305.309	(°C) 0 6 0 65	42 Columns Resist F (O) 0.06613279 0.0661374 0.0713841 0.1308047	39.404 Pr hm) Vdro 0.10 0.11 0.12	int p F (V) 06 15 24 27
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click to s Results – Ad Type Trace Trace Trace Trace Trace	Id Location Internal Internal Internal	Modif Chart 5x5Airl 1ozAirl 3ozVa IPC	Fr41ozp005 IntPoly07 cIntPoly07	Pelete Thickno 0.00120 0.00120 0.00120 0.00120 <u>CI</u> Th	ess (n) V 00 ( 00 ( 00 ( hart	Width (n) 0.010 0.010 0.010 0.010 0.010	Length (n) 1.000 1.000 1.000 1.000 1.000	Area (mi^2) 12.00000 12.00000 12.00000 12.00000	Current (/ 1.736 1.736 1.736 1.736	A) De 10. 31. 54. 280	Density (V ta T ('C) 00000 13496 19120 0.30965	Temp F 35.0000 56.13490 79.19120 305.3090	(°C) 0 6 0 65	42 Columns Resist F (0) 0.0613279 0.0661374 0.0713841 0.1308047	39.404 Pr hm) Vdro 0.10 0.12 0.22	int p F (V) 06 15 24 27
click to s Results Ad Type Trace Trace Trace Trace	Id Location Internal Internal Internal	Modif Chart 5x5Airl 1ozAirl 3ozVac IPC	Fr41ozp005 Fr41ozp007 clntPoly07	Pelete Thickn 0.0012C 0.0012C 0.0012C 0.0012C 0.0012C Th	ess (n) V 00 ( 00 ( 0) ( 0	Width (n) 0.010 0.010 0.010 0.010 0.010 0.010	Length (n) 1.000 1.000 1.000 1.000 1.000 a is set	Area (mil^2) 12.00000 12.00000 12.00000 12.00000 12.00000	Current (/ 1.736 1.736 1.736 1.736 1.736 0.00	A) De 10. 31. 54. 280 rd tl	bisspation           Density (V           sita T (*C)           00000           13496           19120           0.30965	Temp F 35.0000 56.13499 305.3099	(°C) 0 0 6 0 65 0 0 65 0 0 0 0 0 0 0 0 0 0 0 0 0	42 Columns Resist F (O 0.0661374 0.0713841 0.1308047 rd	39.404 Pr hm) Vdro 0.10 0.12 0.22	int p F (V) 06 15 24 27

Figure 1. Charts

		Michael R. Jouppi				-	- L X
e Edit ETC He	elp						
Settings							
Configuration	Mike_fav	-	💌 In	temal 💦 🔿 Exte	emal	Туре:	Trace 💌
Thickness Table	IPC Minimum B	External 💌	Charts	IPC	-	Conduc	tor: 0.5oz Copper
Calculator Sizing					Electrical		
ross Sectional Are	ea (mil^2) 12.00	Hold			Conductor Length (in)	1.000	Hold
onductor Thickne	ess (in) 0.001	1200			Ambient Temp (°C)	25.00000	305.30965
Conductor Width	h*(in) 0.01	10				Initial State (0)	Final State (F)
Current * (A	1.73	36			Resistance (Ohm)	0.0628811	0.1308047
Cultone (	V 1000				Voltage Drop (V)	0.109	0.227
Temperature Rise	e*(°C)	50565			Power Dissipation (W	0.189	0.394
click to solve para	ameter.	Reset			Power Density (W/in'	2) 18.942	39.404
Results					/		
Add	Modify	Delete	۱	/		Columns	Print
Trace Internal Trace Internal Trace Internal Trace Internal	I 5x5AirFr41o; I 1ozAirIntPol; I 3ozVacIntPol I IPC	2p005 0.001200 y07 0.001200 oly07 0.001200 0.001200 Calculate other two	any one varia	12.000000 1.7 12.000000 1.7 12.000000 1.7 12.000000 1.7 12.000000 1.7	736         10.00000         35.0           736         31.13496         56.1           736         54.19120         79.1           736         280.30965         305.	0000 0.0613279 3496 0.0661374 9120 0.0713841 30965 0.1308047	0.106 0.115 0.124 0.227
		Get all of described dissipation the trace	The critical p in IPC 2152, on and power that you speci	arameters such as tra lensity for fy.	s that are ace power the length of		

Figure 2. Calculations

ThermalMan Calculator	
Conductor: 1-302 Copper	
	Location: Internal
Calculator	
Conductor Thickness (in) 0.00135	Conductor Length (in) 1.00000
Cross Sectional Area (mil <sup>2</sup> )	Ambient Temp (*C) 25.000 35.000
Conductor Width * (in)	Initial State * Final State *
Current*(A)	Resistance (Ohm)
Temperature Rise * ("C) 10.000	Voltage Drop (V)
* click on buttons with an asterisk to solve for that parameter.	Power Dissipation (W)
Reset All Values	Power Density (W/in^2)
Add Modify Delete	Columns Print
Type Location Method Thickness (in) Width (in) Length (in) Area (mil^2) Current (A) Delta T ('C) Temp 0 ('C) Res	sist 0 (Ohm) Vdrop 0 (V) Power 0 (W) Density 0 (W/in^2) Temp F (*C
Trace Internal 1ozAirIntPoly07 0.00135 0.00% 1.00000 11.895 1.000 10.000 25.000 0.00	63 0.063 0.063 7.204 35.000
Via Internal 1ozAirIntPoly07 0.00100	18 0.018 0.018 0.567 35.000 11.586 35.000
If you are participating in CAT testing a	at Conductor
Analysis and Test Inc. Take advantage	of the data that
you have and include it in the Weight T	able III and
IDC minimum allowable walves are included	
IPC minimum allowable values are included	uded.
Research has shown that the resistivity of	of loz copper
and oreater has a different value than $\frac{1}{1/2}$	oz conper
This issues to assist and the state of the s	
I his impacts resistance, voltage drop an	la power
calculations. They are included in the c	onductor
selection.	
4	Þ

Figure 3. Conductor Analysis Test Data and Weight Table

ThermalMan Calculator				_ 8 >
Settings Chart TozAirIntPoly07 💌	Conductor: 1-3oz Copper 💌		Type: Via	I
Configuration Mike_Test	Weight Table Underwriter Laboratory 🗾	Via Depth (in)	Location: Trace Via Therm 1.00000	nal dded Resistor
Cross Sectional Area (mil^2)		Ambient Temp (*C)	25.000	35.000
Via Diameter (in) Current * (A) Temperature Rise * (*C) * click on buttons with an asterisk to solve for that parameter. Reset All Values		Resistance (Ohm) Voltage Drop (V) Power Dissipation (W) Power Density (W/in^2)		
Add         Modify         Delete           Type         Location         Method         Thickness (in)         Writh (in)           Trace         Internal         IozAirlmPoly07         0.00135         0.0030           Via         Internal         IozAirlmPoly07         0.00100         0.0081	Length (in) Area (mi <sup>(2)</sup> ) Current (A) Detta T (C) Temp 0 (C) Resist 0 100000 11.895 1.000 25.000 0.063 42.394 1.000 25.000 0.018 Included is the utility to calculate capacity of vias and thermals. For vias, the input parameter now width to Via Diameter. The calcu copper cylinder based on the via of thickness that you choose. All values calculated can be added can be saved as a comma-separate	(Ohm) Verop 0 (A) Power ( 0.063 0.018 0.018 the current ca changes from lation is throw liameter and o d to the Log 7 ed-variable ou	Column <sup>2</sup> (W) Density 0 (W 7.204 0.567 arrying arrying n trace ugh a copper Fable that 1tput file.	ns Print /in^2) Temp F (°C 35.000 35.000 35.000
<b>a</b>				F

Figure 4. Vias and Thermals

ThermalMan Calculator		X
ThermalMan Calculator  File Edit Ejo Help  Settings Chart: 1ozAirIntPoly07 Configuration Mike_Test Calculator Conductor Thickness (in) 0.00100 Cross Sectional Area (mil*2) Via Diameter* (in) Current* (A) emperature Rise * ('C) 10.000 * click on uttons with an asterisk to solve for that parameter. Results Results Results Results Via Diameter Thickness (in) Wrid Trace Internal 1ozAirIntPoly07 0.00135 0.03 Via Internal 1ozAirIntPoly07 0.00100 0.00	Conductor:       1-3oz Copper         Weight Table       Underwriter Laboratory         Thermal Man Preferences       Image: State of the stat	Type:       Via         Location:       Internal         ✓       Mia Depth (in)       1.00000         Ambient Temp (*C)       25.000       35.000         Initial State *       Final State *         Pesistance (Ohm)
For the conve units are inclu- preferences the work in and se are calculation Then <b>Save</b> the	enience of the user, both English and uded in the preferences section. In the user can select the units they wan set the precision of the parameters the g. ose parameters as a configuration.	I SI he t to at they

Figure 5. Preferences

Thermo File Edit Cdart Cdart Cdart Consesse Con	Hen Calculator Etc Help	1-3oz Coppe by Underwriter I Underwriter I I Current (Arr 8.000 10.001 8.000 10.001 8.000 10.001 8.000 10.001 8.000 10.001 8.000 10.001 8.000 10.001 8.000	r aboratory  Thermal Man Prefer  Thermal Man Prefer  Thermal Man Prefer  Thickness Midth Length Area Temperature Current Resistance Voltage Deuxe	Trees Longth (me Ardbert Tenue of Ardbert Tenue of S Weights Column Mike's Preferences ents/My Pictures/Sunli Units Inch	type           1.00           25.000           25.000           Initial Standard           nwater.jpg              Precision           5           2           3           3           5           4	Copper Internal 38 2 × 2 ×	LIS X
Trace Trace Trace	calculator so that you can store your	8.000 10.000 8.000	Temperature Current	Degrees C 💌	] [3 ] [3	4 4 4	99 50 95
Trace Via	favorite picture as a <b>Background</b> <b>Image</b> .	10.000	Resistance Voltage Power Power Density Thermal Conductivity Desists it :	Ohms  Volts Ohm in 22 (in	5       4       3       3       3	বদ বদ বদ বদ বদ বদ বদ	95 58
			Qose	Save	Delete		

Figure 6. Features

ThermalMan Calculator		X
File Edit Etc Help		
Chart: 1ozAirIntPoly07  Configuration Mike_Test	Conductor: 1-3oz Copper 💌	Type: Via 💽
Calculator	Preferences Materials Weights Columns	
Conductor Thickness (in) 0.00100 Cross Sectional Area (mil^2)	Name 1-3oz Copper Material Type	pth (in) 1.00000 nt Temp (*C) 25.000 35.000
Current*(A)	Material Properties	ance (Ohm)
Temperature Rise * (*C) 10.000	Thermal Conductivity (W/in-C) × 9.940	e Drop (V)
* click on buttons with an asterisk to solve for that parameter.	Thermal Conductivity (W/in-C) Y 9.940	Dissipation (W)
Reset All Values	Conductor Properties	
Add         Modify         Delete           Type         Location         Method         Thickness (in)         Width (           Trace         Internal         10zAirIntPoly07         0.00135         0.0088           Trace         Internal         IPC         0.00135         0.0314           Via         Internal         10zAirIntPoly07         0.00100         0.0081	Weight (oz)         1.000           Resistivity (mOhm-in)         0.00070900           Base Temperature (C)         25.000           Temperature Coefficient (1/deg C)         0.038536           Add         Mod         Del           Name         Type         ThermalConX (Win-C)         ThermalConX (Win-C)           1-302 Copper         Conductor         9.40         9.941           Cyante Ester – S-Glass         Insulator         0.009         0.009           G10         Insulator         0.012         0.012           Holometrix FR4         Insulator         0.012         0.012           Holometrix FR4         Insulator         0.008         0.008           Phenolic (XXP)         Insulator         0.012         0.012           Holometrix FR4         Insulator         0.009         0.005           Phenolic (XXP)         Insulator         0.012         0.012           Holometrix FR4         Insulator         0.012         0.012           Holometrix FR4         Insulator         0.013         0.011           IEC FR4         Insulator         0.015         0.011           Polyimide – Glass         Insulator         0.015         0.011	Columns         Print           rop 0 (V)         Power 0 (W)         Density 0 (W/in^2)         Temp F (*C)           063         0.063         7.204         35.000           018         0.0567         35.000           034         0.094         11.586         35.000
Board material properties a in the x and y axis, as well	are included for each test board. The th as the z-axis for the FR4 and Polyimide	ermal conductivity e test boards.
database is included for use <b>Calculator</b> .	e with the <b>Equivalent Thermal Condu</b>	ictivity

Figure 7. Board Properties

<u>E</u> dit E <u>t</u> c <u>H</u> elp								
ettings hart IPC configuration Jouppi1	•		Conducto Weight T	or: 0.5oz Copp able Underwrite	er 💽		Type: Location:	Trace 💌 Internal 💌
alculator conductor Thickness (in) tross Sectional Area (mil^a	2)	0.00070				Conductor Length (in) Ambient Temp (*C)	1.000	
Conductor Width	🖁 Equivilant Th	ermal Conductivity					? ×	al State *
Current*(A	Laver Type	Material	Pct Conductor	Thickness (in)	Thermal-Con X (W/in-C)	Thermal-Con Y (W/in-C)	Thermal-Con Z (W/in-C)	
Tomporatura Pia	1 Signal	0.5oz Copper	- 20.00000	0.00135	9.94000	9.94000	9.94000	
remperature His	2 Dielectric	Holometrix Polyimide	• 2.00000	0.01500	0.01380	0.01380	0.00850	
lick on buttons with an e	3 Power	0.5oz Copper	70.00000	0.00135	9.94000	9.94000	9.94000	-
Res	4 Dielectric	Holometrix Polyimide	2.00000	0.01500	0.01380	0.01380	0.00850	
	5 Ground	1-3oz Copper	70.00000	0.00135	9.94000	9.94000	9.94000	
esults	6 Dielectric	Holometrix Polyimide	2.00000	0.01500	0.01380	0.01380	0.00850	
Add Modify Fype Location Cha	/ Signer	• ULboz Copper	20.00000	0.00135	9.94000	9.94000	9.94000	Print ) Resist F
	7		-Board D	imensions		-Equivalent Th	ermal Conductivity	
			Width (ii	1.000	-	Width X /W/in	-C) 0.49133	
/	<u>Export</u>		Length (	in) 1.000	-	Length Y (W/i	n-C) 0.49133	
	<u>C</u> lose		Depth (i	n) 0.050		Depth Z (W/in	-C) 0.23014	

The Equivalent Thermal Conductivity Calculator is an aide for estimating the equivalent thermal conductivity of a board stack up. This accounts for external and internal copper planes and dielectric material.

Material properties in the database are available for the user or the user can input their own. Then the user defines the board dimensions, width, length, thickness and the number of layers. The user then defines the thickness of each layer and the percent copper on power, signal and ground layers.

This calculator is an aide for understanding what the trace heating will be in other board materials. If the effective thermal conductivity of the material is higher than the raw board material then the traces will run cooler. The important aspect to consider is that the traces dissipate power.

Figure 8. Equivalent Thermal Conductivity Calculator

ThermalMan Calculator		
<u>File Edit Etc Help</u>		
Settings	Conductor 13az Connor	Tuno: Via
Configuration Mike_Test	Weight Table Underwriter Laboratory	Location: Internal
Calculator		
Conductor Thickness (in) 0.00100		Via Depth (in) 1.00000
Cross Sectional Area (mil^2)		Ambient Temp (*C) 25.000 35.000
Via Diameter*(in)		Initial State * Final State *
Current*(A)	Thermal Man Preferences	Price (Ohm)           Price (Ohm)
Temperature Rise * (*C) 10.000	Preferences Materials Weights Columns	Dissipation (W)
Reset All Values	T Charl	Density (W/in^2)
Add Modify Delete	Internal/External	Columns Print
Type Location Method Thickness (in) Widt	h	rop 0 (V) Power 0 (W) Density 0 (W/in^2) Temp F (*C
Trace Internal 1ozAirIntPoly07 0.00135 0.000	38	0.063 0.063 7.204 35.000
Via Internal 1ozAirIntPoly07 0.00100 🗶 0.00	31 🔽 Conductor Length 🔽 Xsection Area	034 0.094 11.586 35.000
1 /	Conductor Width	
	Conductor Thickness Conductor Rise	
	InitialTemperature     FinalTemperature	
The Columns in the	Initial Resistance     Initial Voltage Drop     Initial Voltage Drop     Initial Voltage Drop	
table are turned-on for	Initial Power Dissipation	
display and turned-off	✓ Initial Power Density ✓ Final Power Density	
when only specific		
values are of interest		
values are of interest.	<u>C</u> lose <u>All</u> <u>N</u> one	
The Table can be saved		
as a comma-separated-		
variable file as		)
mentioned previously or		
simply sent to your		
printer		
princer.	Figure 9. Table Preferences	
	3	