NANOTHERM®

Application Note

Designing a Nanotherm LC MCPCB

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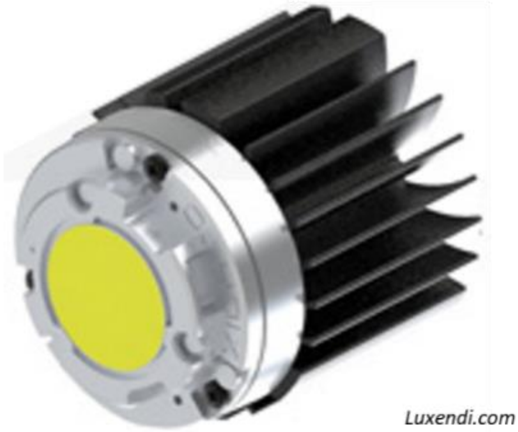
Commercial in Confidence

Contents

1. Introduction

Commonly, printed circuit boards (PCBs) are made from a material called FR4 or one of its various cousins. FR4 PCBs have many merits, which explains their widespread use. However, organic resin PCBS are very bad at removing heat from electronic components. Many will be familiar with the inside of a computer where the microprocessor is attached to a massive fan-assisted heat sink to keep the temperature of the semiconductor within a safe regime. Two other types of electronic component that require careful attention to thermal management is power semiconductors and LEDs.

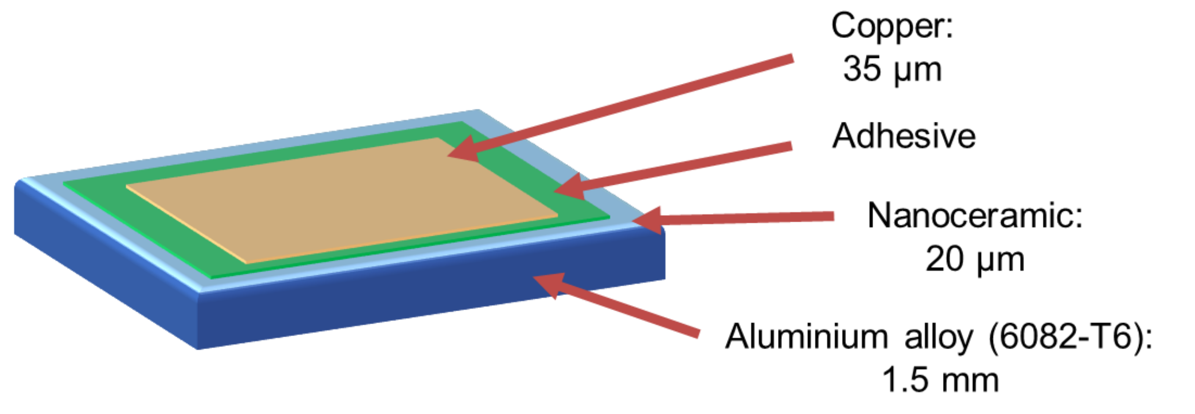
	
Stereo audio amplifier with power MOSFETs mounted on common heat sinks	High power LED module attached to a heat sink

2. MCPCBs

For applications where there is a need to keep electronic components cool Metal Core PCBs (MCPCBs) are used. An MCPCB consists of a plate of aluminium or occasionally copper, around 1.5mm thick. It is this metal core than ensures the easy passage of heat through the thickness of the board from the component to the heat sink. On top of the metal core is applied a copper foil, which is patterned and then completed with solder mask and a coating applied to the lands, exactly as with a standard FR4 board. The copper foil cannot be bonded directly to the metal core otherwise there would be an electrical short. To overcome this problem a thermally conductive dielectric layer (i.e. electrical insulator) is inserted between the copper tracking and the aluminium core. The technical challenge and key to differentiation between competing products is the material system selected for the dielectric; it must provide the right balance of thermal, electrical and mechanical properties, as well as cost.

Cambridge Nanotherm uses an ultra-thin (10-20um) layer of nanograin alumina as the dielectric. This is manufactured in an electrochemical cell, where the surface of the aluminium metal core is converted to nanograin, alpha-phase alumina. Because the dielectric is created by conversion of the surface of the aluminium plate, it is perfectly adhered and presents virtually no thermal impediment to the passage of heat across the interface. Nanograin alumina ceramic is an excellent dielectric (50-75V/um), so that the layer can be extremely thin yet permit the copper tracking to be at a high potential relative to the heat sink. Keeping the dielectric layer thin also helps the thermal performance since the thermal impedance of a layer is its thickness divided by the thermal conductivity (20-30W/mK for alumina and slightly lower for the material in nanograin form).

A judiciously selected adhesive is used to attach the copper foil to the surface of the nanograin alumina. This is done using a laminating process, hence the product name “Nanotherm LC”, where LC stands for ‘laminated copper’.



Concept drawing of a Cambridge Nanotherm LC MCPCB. In practice all four layers are equal in area.

Nanotherm LC has the best thermal performance of any MCPCB available commercially, worldwide. For a typical 1.5mm thick MCPCB with a 35um thick copper foil, the thermal resistance from the top side of the copper to the underside of the aluminium will be less than 0.31°C.cm^2/W. It must be stressed that thermal engineering is a relatively complex subject and there are many good reasons why thermal conductivity (units W/mK) is an inappropriate thermal metric to use in conjunction with MCPCBs. The correct units are thermal resistance (°C.cm^2/W) for a product and thermal impedance (°C/W) for each unique design of MCPCB.

3. Construction of Nanotherm LC

With few exceptions, all commercially available MCPCBs have the same construction. The boards have up to five layers, with offering different options for each layer. Hereafter, reference will be made exclusively to Nanotherm LC products.

- Aluminium core. The standard thickness of aluminium alloy core is 1.5mm. That thickness includes the nanograin alumina dielectric layer. The aluminium alloy is 6082-T6. Circuit dimensions can be up to 285 x 437 mm presently, with expansion to 285 x 590 mm expected in 2019.

- Copper tracking. The standard copper thickness is 35um (1 oz). For a very limited number of circuit designs there may be a need to increase the copper thickness to 70um (2 oz), due to either the passage of exceptionally high currents or to aid cooling of very particular components. Cambridge Nanotherm has the capability to run electrical and thermal simulations and can advise whether 2oz copper is truly necessary.
- Copper pad finish. All standard pad finishes can also be applied to an MCPCB. For reasons of cost and to shorten product delivery lead time it is recommended that consideration is given to Organic Solderability Preservative (OSP) and electrolytic nickel – immersion gold (ENIG).
- Solder mask. There exist many different types of solder mask and each of Cambridge Nanotherm's manufacturing partners have their own preferences and supply chain. If it is required the MCPCB has a UL marking, then the choice is restricted to ElectraPolymers EMP110W or Tayio PSR-4000 LEW3. Both of these have high optical reflectivity and appear brilliant white. Typically, the solder mask will be 20um thick, but some variation is possible.
- Ident / Legend / Silk screen marking. This layer, which has multiple names, is essentially any "writing" on the board. On white solder mask the legend is usually black, but alternative colours to complement the chosen solder mask are available.

Each of these five layers is subject to a set of design guidelines, an explanation of which is set out in the following section.

4. Nanotherm LC design guidelines

Manufacture of an MCPCB is subject to design rules. Owing to the interdependencies between the various layers and manufacturing processes the complete design rule documentation is substantial and complex. To aid customers, a simplified version is set out below. If the proposed design meets all guidelines, generally there will not be a problem with manufacture. The guidelines are specifically called guidelines rather than rules because infringement does not necessarily mean the design is not manufacturable. Cambridge Nanotherm uses a network of worldwide manufacturing partners, each of whom has different capabilities. The table below is an amalgamation of the worst case for every parameter from all partners, so is very conservative. In instance that a proposed design does not meet the guidelines, Cambridge Nanotherm can review and can comment on aspects like selection of manufacturing partner, product volume, lead time, cost, yield risk etc. that may permit production without undue changes.

Ref.	Property / Material	Parameter	Guideline
1	Sidedness	Circuit layout	Single-sided only
2	Electrical	Withstand	2,120V DC (equivalent to 1,500V AC)
3	Aluminium alloy	Area	285 x 437 mm
		Thickness	1.0, 1.5 mm (standard), custom to max 3.2 mm

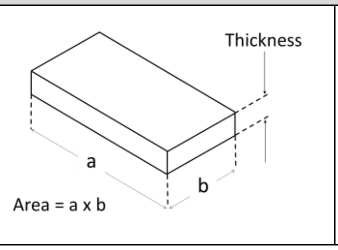
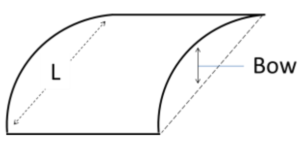
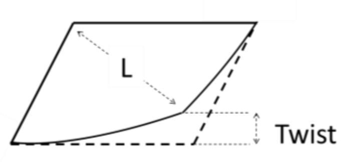
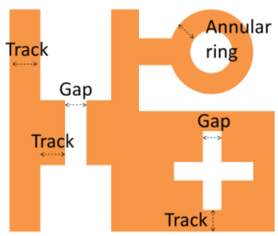
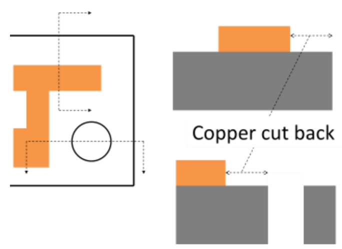
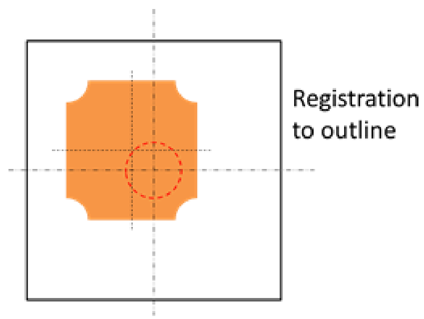
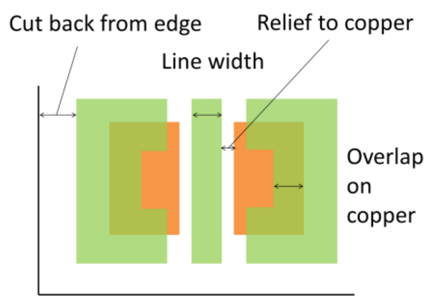
		Alloy	6082 (standard), 6061	
		Warp (bow and twist)	0.50% L	
		Underside finish	Brushed	
4	Copper tracking	Thickness	35 um (1 0z, standard)	70 um (2 Oz)
		Track width	150 um	200 um
		Gap (space) between tracks	150 um	200 um
		Annular ring diameter	300 um	400 um
		Finish	Organic solderability preservative OSP, ENIG (typ. 3 um Ni, 0.1 um Au) ENEPIG (typ. 3 um Ni, 0.1 um Pd, 0.1 um Au) Immersion silver IAG (typ. 0.15 um)	
		Cut-back from routed/v-score edge or mechanical feature	250 um	
		Cut back from punched edge	Same as aluminium thickness	
		Cut back for 1.5KV AC creepage	1.45 mm	
		Mechanical registration to outline	+/- 50 um	
		Minimum character height for etched nomenclature	1.5 mm	
5	Solder mask	Type	LEW-3	EMP110
		Colour	White	LED white, white, black, green, red, blue
		Thickness	20 um +/- 5 um permissible range 10-50um	10-20 um
		Line width	125 um (1oz copper) 150 um (2oz copper)	75um (1oz copper) 100um (2oz copper)
		Minimum cut back from routed/v-score edge or mechanical feature	100 um	50 um (1 oz copper) 75 um (2oz copper)
		Relief to copper	100 um	
		Solder mask overlap on copper pad (optional)	250 um	
		Cut back from punched edge	Same as aluminium thickness	
		Character height / line width in solder mask	500/200 um	
6	Ident / legend / silkscreen	Colour	Black, yellow, white	
		Width	150 um	
		Gap	150 um	
		Character height	1.5 mm	

		Cut back from pad, routed/v-score edge or mechanical feature	200 um
		Ident on pad	Not permitted
7	Marking	UL	Restricted permutations*
		Makers	Yes
		Date / lot	To panel level
8	Holes	Diameter	1.2 mm in <1.5 mm aluminium 1.5 mm in 1.5 mm aluminium 1.8 mm in >1.5mm
		Registration to copper	+/- 150 um
9	Slots	Trench width	2.0 mm
		Internal radius	0.8 mm
		Registration to copper	+/- 150um
10	V-score	V-cut angle	30°
		Web thickness	200 um +/- 100 um (1.0 mm aluminium) 300 um +/- 100 um (1.5 mm aluminium)
		Copper cut back from centre line	1.5 mm
		Solder mask cut back from centre line	1.3 mm
		Registration to circuit	+/- 250 um
		Registration score-to-score	+/- 150 um
11	Inspection	Visual	IPC-A-600H Class2
		Electrical	Open / short, withstand
		Mechanical precision	ISO 2768 fine, med (standard), coarse
		Burrs	ISO 13715
		Cross-out rate	% or number required
12	Quality control	First article inspection report	Provided with first sample of each part number
		Customer IQC	Product specification (necessary to fix Nanotherm OQC criteria)
		8D investigation report	Provided where non-conformance to customer IQC or field returns are received
13	Drawings	File format	Gerber** of circuit and customer unit where panel perimeter contains features defined by the customer.

** UL marking is restricted to Nanotherm LC MCPCBs processed by manufacturing partners Spirit Circuits Ltd., Elvia Printed Circuit Boards Groupe, B.R.E.E SA or Asupi Enterprises (Shenzhan Xingxhiguang). In addition, the MCPCB must be:1.0 mm or thicker, 35-102 um copper, Electra Polymers EMP110W or Taiyo PSR 4000 LEW-3 solder mask, copper finish OSP, ENIG, ENIPIG, or IAG.*

** Gerber drawings are required to manufacture. They should be inside a .rar or.zip archive with standard file extensions:

Extension	Layer
pcbname.GTL	Top copper
pcbname.GTS	Top solder mask
pcbname.GTO	Top silkscreen / ident
pcbname.GBL	Bottom copper
pcbname.GBS	Bottom solder mask
pcbname.GBO	Bottom silkscreen / ident
pcbname.TXT	Hole and slot location and dimensions
pcbname.GML/GKO	Board outline

Ref.	Design guideline		
3			
4			
			
5			

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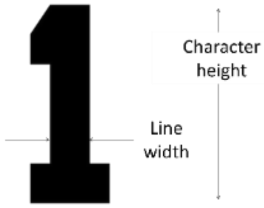

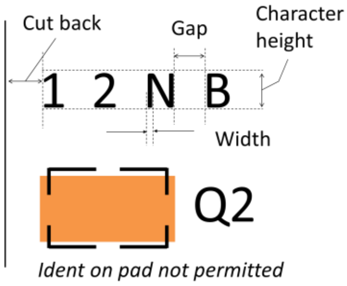

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CNL LCA V-0
E364088

UL mark

CNL mm/yy xx

Makers mark

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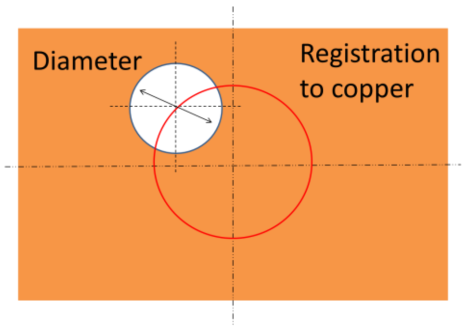

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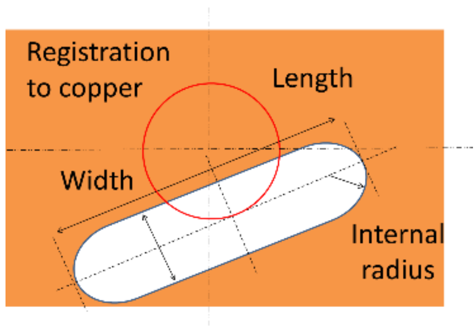

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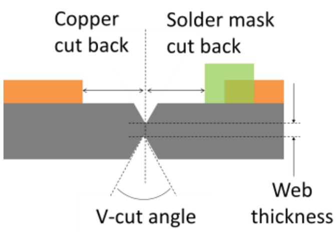
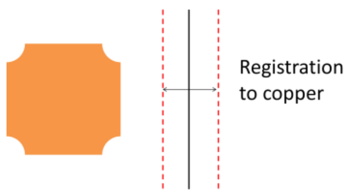
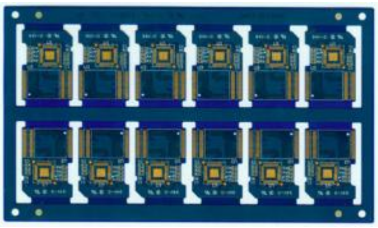
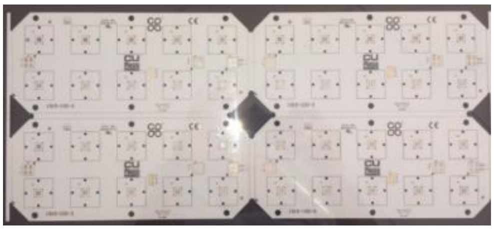




5. Circuits, customer units and panels

The MCPCB industry uses specific nomenclature to differentiate how the product is delivered to the customer:

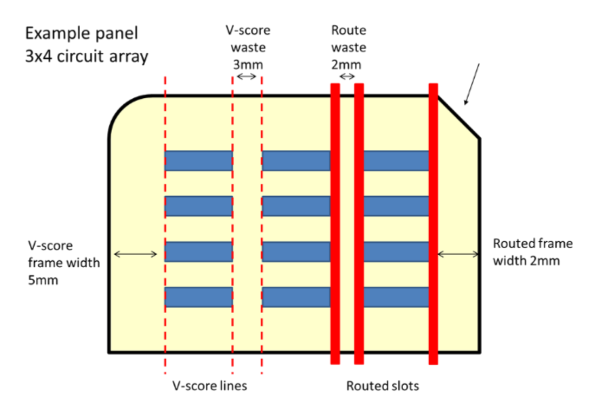
- Circuit. A collection of tracks with a defined boarder, i.e. one functional unit. No further sub-division is undertaken for incorporation in a product.
- Customer unit. This is the form the MCPCB is delivered to the customer. It may be a single circuit or array of circuits or an entire panel. Where the customer unit is an array of circuits these are often provided with a frame that has tooling holes and fiducials to aid placement of the components.
- Panel. Substrate processed by Cambridge Nanotherm and it's MCPCB manufacturing partners. For efficiency and economy, the challenge is always to fit as many customer units as possible on a panel.

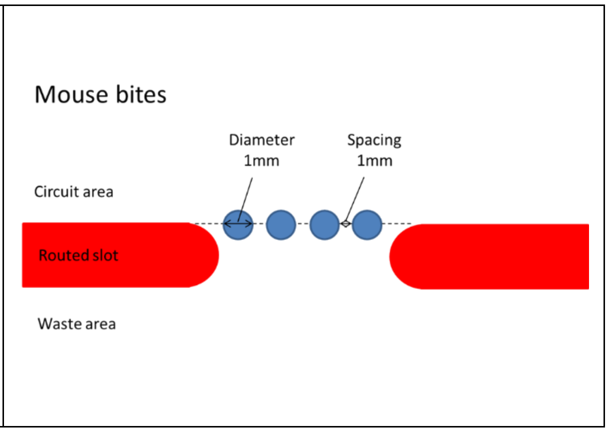
		
Circuit – can vary in dimensions from a few mm per side to over 400mm.	Customer unit, containing 12 circuits within a frame that has tooling holes and alignment fiducials.	Processed panel, carrying four customer units, each of which contains 10 circuits within a frame.

Panelisation also is subject to design guidelines. Mostly these relate to mechanical aspects to ensure the panel has adequate structural integrity for processing and handling, and to ensure the circuits are not damaged when removed from the panel.

Property	**Guideline**
Panel dimension	285 x 437 mm
Corner profile	Rectangular, chamfered, rounded (specify radius)
V-scored frame width	5 mm
Routed frame width	2 mm
V-score-to-v-score	3 mm

Route-to-route	2.6mm OR overlapping
Mouse bites	Diameter 1 mm
	Spacing 1 mm

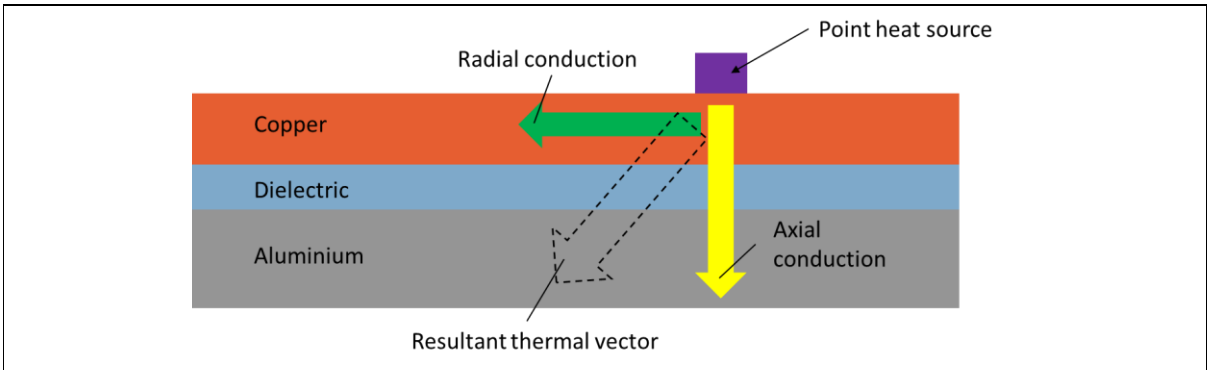




6. Principles of thermal design

The purpose of using a MCPCB in place of a conventional PCB is to remove heat efficiently from electronic components. This means the board layout not only has to provide an electrical function but a thermal one.

Heat transport though a MCPCB is a combination of radial spreading in the copper tracking and axial conduction through the copper, dielectric and aluminium to the heat sink. The resultant thermal vector is a combination of these two pathways.



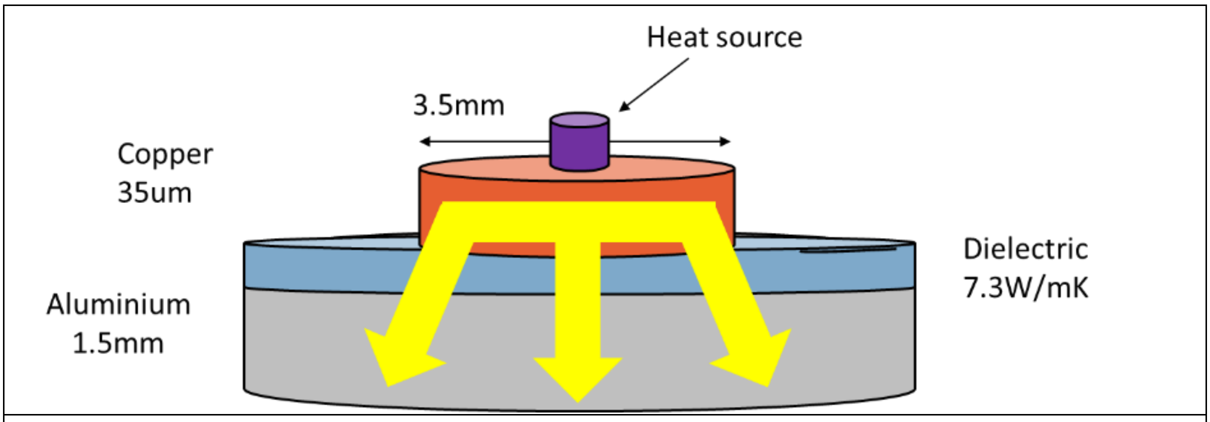
Heat transport pathways in an MCPCB

As can be seen from the above diagram, a large area of thick copper will be beneficial in extracting heat. But there are good technical and commercial reasons why thick copper is should be avoided. In particular, thick copper:

- Cannot be patterned into fine tracks and narrow gaps, necessary for many components (see Design Guidelines, above)
- Increases cost and weight of the MCPCB
- Provides only marginal benefit to the thermal performance and can actually increase the thermal resistance if the area is too small since the heat has to travel through the copper to reach the heat sink
- Often increases the delivery lead time and can hurt yield due to the extra handling and processing involved.
- Is harmful to the environment due to increased chemical and electricity consumption

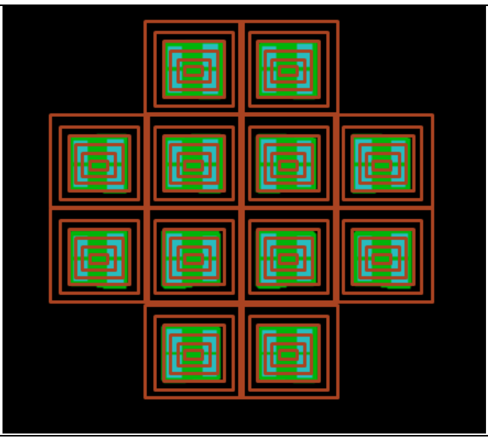
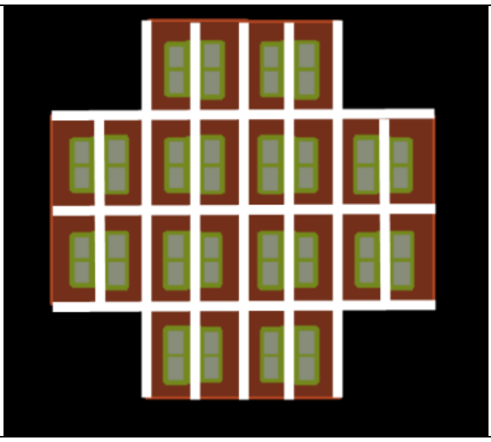
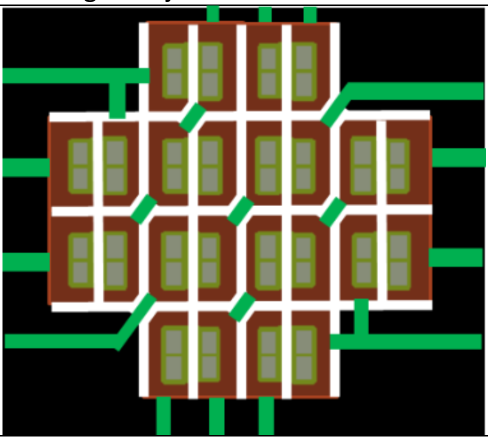
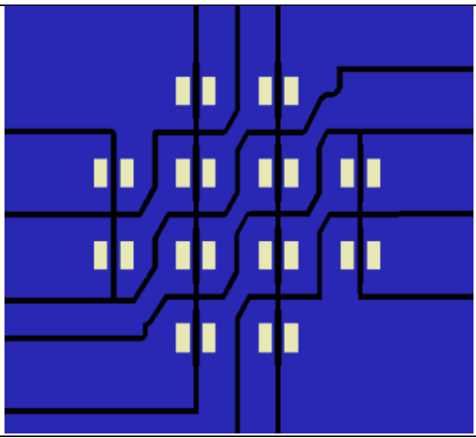
There are very occasional instances where thick copper is necessary due to the electrical current the tracking must carry. Due to the superior thermal performance of MCPCBs this is seldom a consideration, as explained in the next section. For the vast majority of applications that use Nanotherm LC MCPCBs, 35um (1oz) copper is a good choice.

Using thermal modelling it is possible to predict that for a Nanotherm LC MCPCB comprising 35um copper on 1.5mm aluminium, cooling a point heat source, the optimum copper area is a circle 3.5mm diameter. A larger copper area is desirable whenever practical, but beyond a 3.5mm diameter disc the Law of Diminishing Returns applies.



Copper diameter for optimum cooling on a standard Nanotherm LC MCPCB

A common requirement is for the MCPCB to provide cooling to an array of components. In this instance there is a conflict between the layout for electrical function and the copper area required to remove heat effectively. A simple thermal design methodology is to proceed as follows:

	
1) From the centre of each component draw concentric rectangles until adjacent rectangles adjoin	2) Divide copper into islands having 150um gaps, as per Design Guidelines
	
3) Join islands with 150um tracks to form wiring trace and trim corners of copper islands (150um gap) to fit diagonal connections	4) Example design

7. Current carrying ability

The high thermal conductivity of Nanotherm LC MCPCBs means the copper wiring trace can safely carry high currents without fusing. A convenient means of determining the minimum track dimensions for a given current is to use a calculator for FR4 (following specification IPC-2221), based on a 20°C temperature rise and multiply the result x30.

For the minimum track width of 150um in 35um thick copper on a Nanotherm LC MCPCB, the safe current carrying ability is 25A.

8. Conclusions

Nanotherm MCPCBs possess exceptional through-thickness thermal conductivity on account of the unique Nanoceramic material used for the dielectric and the thinness of that layer. Standard product is single-sided and based on 1.5mm thick aluminium, 35um copper, white solder mask and black ident, possessing a thermal resistance of less than 0.31°C.cm^2/W. The design guidelines for Nanotherm LC MCPCBs are not especially different to any other volume manufacturer for this type of product. Cambridge Nanotherm can provide electrical and thermal evaluation of a proposed design and, where appropriate, suggest modifications for optimum performance.