Mechanical Specifications and Basic Heatsink Calculations.

1. MECHANICAL SPECIFICATION

Table 1. Mechanical Tolerances and Specifications unless otherwise specified

Feature	Pressed Components	Extruded Components
Material	Aluminium BS1470 (alloy 1200)	Aluminium BS1474 (alloy 6063)
Overall Dimensions	+/- 1mm	Extruded features BS 1474
Cut to length <300mm	—	+/- 0.25mm
300-500mm	—	+/- 0.5mm
>500	—	+/- 1.0mm
Position of features within the same plane	+/- 0.25mm	+/- 0.25mm
Relative hole centres	+/- 0.15mm	+/- 0.15mm
Surface Finishes		
Standard†	Black Anodised	Black Anodised
On Request	Bright (no finish) Clear Anodised Red Anodised Blue Anodised Gold Anodised Alocrom Hard Anodised*	Bright (no finish) Clear Anodised Red Anodised Blue Anodised Gold Anodised Alocrom Hard Anodised*

† Fan blown units and CJ units are supplied bright as standard
* Hard anodising is not available on all components

Tighter tolerances may be applied to custom and semi-custom components by prior agreement with Redpoint Engineering Dept. Redpoint standard tolerances will be applied to all customer drawings unless tolerances are stated on the drawing.

For further details on tolerancing and machine capability please request a copy of one of the following documents
RQP 3.5.2 "Standard Tolerances for Drawings & Finished Parts"
RQP 3.5.4 "Standard Surface Finishes on Extrusion & Pressings"

2 TESTING

All testing is carried out in accordance with EIA Bulletin No. 5 guidelines using extensive datalogging and computer facilities. All small heatsinks are tested with the device that they were designed for, and mounted on 100 x 100mm FRB PCB. Extrusions are tested using the smallest possible heat source (spot loading), and data is also shown for an evenly distributed heat input where this offers more than 10% increased dissipation over the spot performance.
Redpoint not only has facilities for free convection thermal testing, but also has a full BS848 wind tunnel (over 5m long) for measuring thermal performance in forced convection, and pressure drop as a result of air flow.
The results of much of this testing may be seen in the tables and graphs of this catalogue, however Redpoint has much more detailed data available upon request [please consult Redpoint Sales or Technical Depts].

3 THERMAL CALCULATIONS

3.1 Introduction

Most of the thermal calculations required in electronics may be performed using the Thermal Resistance (Θ measured in $^{\circ}C.W^{-1}$). Θ is a figure which expresses the temperature change required to drive 1 watt across some boundary (ie. chip to package, heatsink to air etc.).

$$\Theta = \frac{dT}{P} \qquad 1.$$

where:— dT= Temperature difference (°C)
P= Heat dissipation (watts)

Almost all of the data required to perform thermal calculations is available in the form of thermal resistance.

Thermal resistance is a very useful concept since it has broadly the same properties as electrical resistance, where temperature corresponds to voltage and heat flow corresponds to current flow. Thus thermal resistances in series add algebraically,

$$\Theta_{TOT} = \Theta_1 + \Theta_2 + \Theta_3 \ldots \qquad 2.$$

and thermal resistance in parallel follow the rules:—

$$\frac{1}{\Theta_{TOT}} = \frac{1}{\Theta_1} + \frac{1}{\Theta_2} \qquad 3.$$

3.2 Θ and Cooling Calculations

Generally thermal situations likely to be encountered in electronics may be expressed diagrammatically as a network of "Thermal Resistors" as shown in fig. 2. In the simplest case of a linear network it can be seen that:—

$$\Theta_{TOT} = \Theta_{J\text{-}C} + \Theta_{C\text{-}S} + \Theta_{S\text{-}A} \tag{4.}$$

where:—

Θ_{TOT} = Total Thermal Resistance
$\Theta_{J\text{-}C}$ = Thermal Resistance Device Junction to Device Case
$\Theta_{C\text{-}C}$ = Thermal Resistance Device Case to Heatsink
$\Theta_{S\text{-}A}$ = Thermal Resistance of Heatsink to Air*

* This is Θ quoted in the Redpoint Catalogue

Heatsink questions normally fall into one of the following categories:—

a. What heatsink thermal resistance ($\Theta_{S\text{-}A}$) is needed to achieve a certain device junction temperature at a certain dissipation and ambient temperature.

$\Theta_{J\text{-}C}$ is known from device manufacturers data, some typical values can be found in Table 2 overleaf.

$\Theta_{C\text{-}S}$ depends on the junction between the device and the heatsink (ie. the use of grease, mica insulators, flexipads etc.). $\Theta_{C\text{-}S}$ can be found in Table 3, or in the specification tables for Flexipads etc.

$\Theta_{S\text{-}A}$ this is what we want to know!!

Θ_{TOT} can be calculated from the maximum allowable junction temperature, the ambient temperature and the power dissipation using:-

$$\frac{(T_{max} - T_{amb})}{P}$$

Thus the equation is as follows:—

$$\Theta_{S\text{-}A} = \Theta_{TOT} - \Theta_{C\text{-}S} - \Theta_{J\text{-}C}$$

b. What is the temperature that the heatsink will reach?:—

$$T_{HSmax} = (\Theta_{S\text{-}A} \times \text{Watts}) + T_{amb}$$

c. What is the maximum power dissipation allowable from a device using a particular mounting arrangement?:—

$$P_{max} = \frac{T_{JNmax} - T_{amb}}{\Theta_{TOT}}$$

Table 2. Some typical values at $\Theta_{J\text{-}C}$ for some common semiconductor packages

General Package Description	Package Type	$\Theta_{J\text{-}C}$ Typical
All Plastic	DIP's PLCC's (68 pin)	14-45 11 approx
Small Plastic but with Metal Tabs	TO220 TO218 Multiwatt	2-7 1-3 1.5-7
Small Ceramic	CerDip's LCC's (68 pin)	3 approx 8+
All Metal	TO3 TO66	1-3 1-5

Table 3. Interface Thermal Resistance for some Common Interfaces. In these tests devices are lagged so that heat loss from the device is eliminated and all heat generated flows through the interface. When used in free air O_{C-HS}°C/W for TO3 devices will be approximately 70% of that indicated below, for plastic package devices little difference will be found.

Interface Medium	Screw Torque cN.M	TO220 Θ_{C-HS}°C/W	TO3 Θ_{C-HS}°C/W	TO218 Θ_{C-HS}°C/W
Bare	40	1.9	0.30	2.4
MICA[2]	40	3.6	1.5	3.8
Thermpath 167	40	0.7	0.15	0.4
MICA[2] Thermpath 167	40	0.9	0.5	0.7
FB Flexipad 0.2 THK	40	2.5[1]	1.00	1.60[1]
FK Flexipad 0.3 THK	40	3.3[1]	1.8	2.5[1]
FSK Flexipad 0.4 THK	40	2.7[1]	0.6	1.0[1]
MICA[2] THICKNESS (mm)		0.04	0.16	0.05

[1] Beware of device lift off due to single screw

10 cN.M = 1 Kg.cm = 0.9 in.lbs.

Thermal Management (by R.D. Johnson)

The author, Dr. R.D. Johnson, is the Technical Director of Redpoint Limited and his paper provides interesting further information with references to other aspects affecting heatsink performance and cooling technology.

1. INTRODUCTION

Thermal management has often been considered the Cinderella of the Electronics Industry. Indeed on many occasions when new advances in device manufacture have been announced the demise of the humble heatsink has been predicted along with all the associated thermal management equipment. Most of these forecasts would have been correct if the products which the electronics are part of did not constantly increase in function and decrease in size.

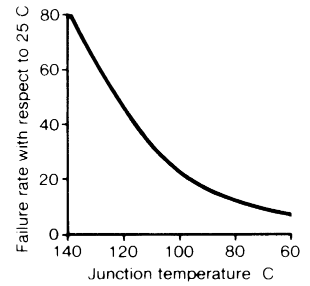
1.1 Why Cool

The generation of heat by electronics is an unavoidable consequence of Ohm's Law and the Second Law of Thermodynamics. Heat will always need to be removed from electronic equipment, however the mere fact of the equipment standing in air in the environment may be sufficient to cool the unit if power levels are low, (eg. the pocket calculator and the standard transistor radio). However when function or power output is increased (ie. moving from a calculator to a computer, or from a transistor radio to a Hi-Fi system) the heat generated increases due to the increased demand on the system.

Electronic units need to be cooled for three basic reasons:—

1. The electronic junctions (at least in silicon) will fail at 175°C (standard plastic packaging will usually fail at around 150°C, above this temperature high reliability packaging is required).
2. The life expectancy of electronic junctions is an inverse function of temperature (see fig. 1). Typically at up to 150°C the life expectancy halves for every 10-15°C, from 155°C to 175°C life expectancy halves for every 5-10°C.
3. The properties of semiconductors change with temperature and it may be necessary to control the temperature of key devices, or to maintain several devices at the same temperature to maintain function.

Fig. 1 Failure rate versus silicon junction temperature



2. COOLING METHODS

2.1 Introduction

There exist only three main tools in the Thermal Management armoury:—

Conduction
Convection
Radiation

However these tools can be applied in a variety of ways some of which have a strong potential for the cooling of increasingly complex electronics. The basic equations for all of these heat transfer mechanisms can be found in a variety of books and articles [1, 2, 3,] and thus only very cursory attention will be given here.

2.2 Conduction

Conduction is probably the first heat transfer mechanism that one learns about at school, mainly because it can be explained in fairly simple terms (at least in 1-dimension), and the equations are analytic (ie. the equations are the same in all situations only a constant changes). Conduction is generally only thought of in connection with solids, however liquids and gasses will also conduct heat to a lesser extent.
The 1-D model of conduction is in many ways an over simplification since the very simple equation (shown in Eqn. 1.) only applies to conduction in one dimension, the equations become rapidly more complex as the move to 2-D and 3-D is made.

Simple 1-D Conduction Eqn. $Q=K.A.dT$ Eqn. 1

Where:—
$Q=$ heat flow (W)
$K=$ Thermal Conductivity of Material ($W.m^{-1}.K^{-1}$)
$A=$ Cross Sectional Area for Heat Flow (m^2)
$dT=$ Temperature gradient ($K.m^{-1}$)

2-D Conduction Eqn. for rectangular box (for illustration only)

$$Q=K.1.685.L.(\log(1+b/a))^{-0.59}.(b/c)^{-0.078}$$ Eqn. 2[a]

The 3-D equation is rather beyond the scope of this paper but can be found elsewhere[1]. The situation can be further complicated in none steady state conditions where the thermal capacity of the conducting medium comes into play.
In many of the electronic situations in which conduction is involved a 1-D analysis is often valid due to the thin layers of the medium through which conduction is required, however there are notable exceptions in the silicon packaging field and in the design of extruded heatsinks[b]. If required a fuller account of the conduction phenomenon can be found in reference 1.

2.3 Convection

Convection is a much feared heat transfer process, but in essence it can be described qualitatively as conduction into a fluid which is free to move. The movement element introduces, fluid dynamic properties into the equations, which may also include buoyancy effects. There are very few situations in convection where analytic solutions[c] exist, however much of this complication is not evident in the equation for convection Eqn. 3 where all of the complexity is hidden inside the determination of "h".

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[a] See Ref. 1 for further details.

[b] Where the situation is not laminar due to large dimensional differences between the heat source and the conducting medium

[c] Analytic solutions are those which comes from first principles. The opposite to analytic is empirical where mathematical descriptions arise out of a rationalisation of experimental results.

Basic Convection Equation $Q=h.A.dT$ Eqn. 3

Where:– $Q=$ heat flow (W)
$h=$ Heat Transfer Coefficient ($W.m^{-2}.K^{-1}$)
$A=$ Surface area for heat transfer (m^2)
$dT=$ Temperature Difference surface and fluid ($K.m^{-1}$)

Thus most of the mathematical tools associated with convection are empirical and thus usually involve a complicated set of caveats associated with the application of a particular set of equations. However if one does not require accuracy to better that about 10% one can use some very simple relationships to define the heat transfer coefficient "h" (see table 1).

Table 1. Formulae for the calculation of "h" for free air at 1 atmosphere pressure at "electronics" temperatures.

		Laminar Flow	Turbulent Flow
Vertical surface	$h_f=$	$1.4\ (dT/L)^{0.25}$	$0.9.dT^{0.33}$
Horizontal surface (Hot up)	$h_f=$	$1.3\ (dT/L)^{0.25}$	$1.2.dT^{0.33}$
Horizontal surface (Hot down)	$h_f=$	$0.6\ (dT/L)^{0.25}$	$0.6\ (dT/L^2)^{0.25}$

2.4 Radiation

Radiation is essentially simple line of sight process which can be represented by a relatively simple analytic equation. Radiation is usually thought of as direct solid to solid heat transfer, but radiation can also be used to couple heat into liquids and gasses under certain conditions.

Equation for Radiation $Q=E.A.(T_1^4 - T_2^4)\ \sigma$ Eqn. 4

The radiation equation is simple as long as a suitable value for the emissivity (E) is chosen (from tables), and the appropriate "projected area"[d] is used. For further information on radiation heat transfer see references 1, 2, 3 and 4.

3. HOW TO COOL ELECTRONICS

3.1 Understanding the Problem

In order to set about the cooling of electronics one first has to understand the nature of the situation. In its simplest form the cooling of electronics can be considered a truly serial situation as shown in fig. 2. In real life however there are usually a complex matrix of heat paths as shown in fig. 3, both situations can be described by an electrical analogy (shown alongside the box diagram) where heat flow is equated to current, temperature difference to potential difference and electrical resistance to "Thermal resistance"[e]. The electrical analogy allows quite complicated situations to be expressed as resistor networks which may then be analysed.

One of the features of electronic systems which complicate the cooling analysis is the fact that often the item to be cooled is a very small silicon die (say 6mm square) buried deep in a package, thus if conduction is a prime mechanism care must be taken if applying the simple 1-D equation, however since device manufacturers usually quote thermal resistance chip to case the problem is not usually encountered by engineers.

Fig. 2 Nested box diagram for a simple system

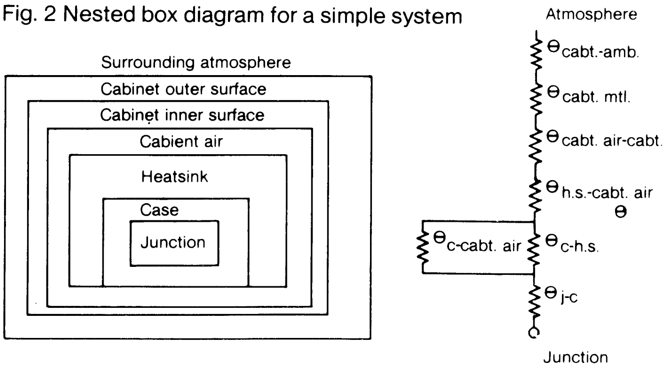
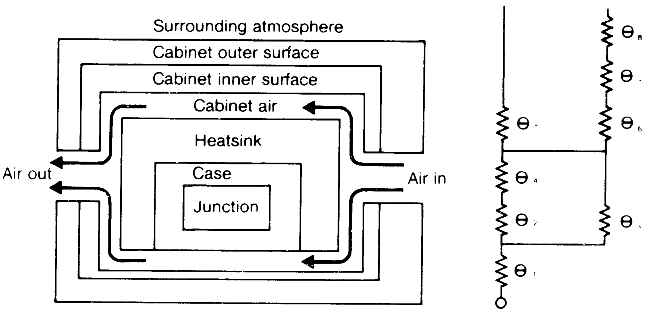


Fig. 3 Nested box diagram for a fan-cooled system



3.2 Analysis of a Simple Cooling Problem

The situation analysed here is represented in fig. 2 and represents a single device in a sealed enclosure. Each step of the heat transfer route will be taken in turn and described and if possible quantified.

3.2.1 $\Theta_{J\text{-}C}$ (junction to case)

The principle heat transfer mechanism between the semiconductor junction and the device casing is conduction. In most situations the semiconductor die is soldered or adhesively bonded to a lead frame which may also be attached to a metal part of the case. The value of $\Theta_{J\text{-}C}$ depends upon the size of the semiconductor die, the attachment method, lead frame construction

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d. "Projected Area" is not the total surface area of the object, but the apparent visible surface area (see ref. 2).

e. "Thermal Resistance" may be considered as the result of evaluating all the fixed parameters of the heat transfer mechanism to give a single °C/W figure.

and the package type. Heat is typically conducted through the die attachment medium into the lead frame and/or the metal part of the case (if any). The thickness of the lead frame material and its thermal conductivity can have a significant impact on $\Theta_{J\text{-}C}$, as does the detailed construction of the semiconductor package. The value of $\Theta_{J\text{-}C}$ is not normally under the control of the design engineer save in the initial component/package selection, and one normally therefore finds that packages are segregated broadly by their $\Theta_{J\text{-}C}$ (which in turn reflects their power handling capacity). In general the package thermal resistance order is as follows:—

General Package Description	Package Type	$\Theta_{J\text{-}C}$ Typical
All Plastic	DIP's PLCC's (68 pin)	14-45 11 approx
Small Plastic but with Metal Tabs	TO220 TO218 Multiwatt	2-7 1-3 1.5-7
Small Ceramic	CerDip's LCC's (68 pin)	3 approx 8+
All Metal	TO3 TO66	1-3 1-5

3.2.2 $\Theta_{c\text{-}h.s}$ (case to heatsink)

The thermal connection between the case of the semiconductor package and the heatsink is usually a relatively simple 1-D conduction mechanism. Unfortunately the situation is slightly complicated by the nature of 2 hard surfaces in contact which in principle always appear as in fig. 4a, only the vertical scale changes. Thus the area of contact between the two surfaces (which is the area used in the conduction equation) is very small, and heat transfer in other areas has to be by either convection or radiation. In this situation a typical thermal performance of the joint can be seen in fig. 4b. In order to improve the thermal performance of the joint it is necessary to increase the contact area between the two hard surfaces by one of two mechanisms:—

1. Increase surface contact by increasing inter surface pressure in order to "squash" peaks.
2. Fill the gaps between the surface with some material which is a better conductor than air (such as Thermpath thermal grease or Flexipads.[f]).

Fig. 4 Thermal resistance between two hard surfaces; (a) typical appearance of two hard surfaces brought together; (b) effect of interface pressure on interface thermal resistance for two pieces of milled aluminium, 1-6 micron surface roughness.

Fig. 4a

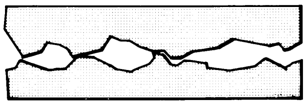
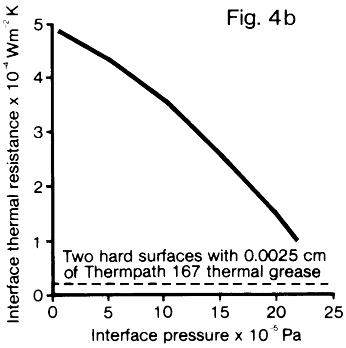


Fig. 4b



3.2.3 $\Theta_{h.s\text{-}air}$ (heatsink to air)

In this situation "heatsink" is a term used for a device used to extend the surface area of the semiconductor package. If no heatsink is used then the following mechanism applies to the surface of the device package. $\Theta_{h.s\text{-}air}$ is made up of two elements:—

1. Convective heat loss from the extended surface of the heatsink into the surrounding air.
2. Radiative heat transfer from the heatsink surface into the surrounding environment.

3.3 Summary

The above thermal resistance steps contain all of the elements of passive cooling, and all of the other thermal resistance steps are slight variations of the above 3 Θ's.

4 REDUCING Θ

In the discussion so far only passive cooling has been discussed and in order to reduce the total Θ of the systems it is necessary to have more control of the construction and operating environment of the electronic system. Initially some common and relatively simple additions to the system will be examined in order to minimise thermal resistance.

4.1 Air Movement & Thermal Resistance

The use of air moving devices are to improve convective heat transfer is a logical progression when one considers that a main feature of convection is the air movement generated by the buoyancy effects of heated air. In free convection at the temperatures which are experienced in electronic systems the typical air velocity generated by convective heat transfer is in a range up to around 0.1 m.s^{1}.

Convection is basically defined as simply conduction into a fluid which is free to move and thus if the fluid moves faster due to an outside influence then the heat transfer should improve, and indeed this is what is found. The improved thermal transfer due to forced convection air flow can be seen in table 2.

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[f] Flexipad is a Redpoint trade name for glass reinforced high thermal conductivity silicon rubber washers, which provide electrical insulation, and improved thermal interface.

Table 2. The -effect of a local air speed on "h" based on "h" for -free air.

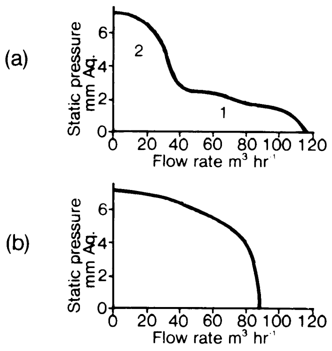
Local Air Speed m.s-1	h
free air	h_f
2.0	2 x h_f
5.0	3 x h_f

Air flow has two basic cooling effects one is associated with improved "h" due to better air movement, the second is due to the effect of improved air circulation in sealed enclosures (see Eqn. 5). More detail on both of these effects can be found in references 1, 2, 3 and 4, however it is important to understand that air flow is generated by pressure differences, but the improved cooling effect is due to flow rate.

The Cooling Effect of Air Volume Flow Through an Enclosure $P = V \times dT / 2.8$ Eqn. 5

Where:—
P= Power Dissipation of Equipt. inside Cabt. (W)
V= Volume Air Flow $(m^3.h^{-1})$
dT= Input/Output change in Air Temperature (°C)

Fig. 5 Typical pressure flow curves of fans used in electronic equipment;
(a) axial type fan pressure-flow curve
(b) centrifugal type fan pressure-flow curve



4.1.1 **Air Flow Mechanics**

The mechanics of air flow are associated with the various fan types and flow parameters of the system through which the air flows. In order for any air to flow a pressure difference must be generated and this pressure difference is generated by some form of fan. The detail mechanisms of air flow have similarities with all other flow systems including current flow in electronic systems. This analogy can be used to better understand the interactions between the various interrelated phenomena.

1. The Fan can be considered as a medium impedance current source. The voltage available to generate the current flow is an inverse function of the current flow. Thus as the current (airflow) increases the voltage (pressure difference) available to drive it reduces. A typical axial fan pressure/flow curve can be seen in fig. 5. Different fan styles and designs have different pressure/flow curves as shown, as can be seen in fig. 5.
2. The system into which the air is forced can be considered as an electrical resistance, the more current flow (air flow) the greater voltage drop (pressure drop) must be available across the resistor (system). The resistance characteristics are not necessarily linear with current (air) flow.

4.2 Other Active Cooling Methods

There exist several other cooling mechanisms which may be classified as active. These include;

Heat Exchangers, in which extended surface areas are used inside and outside the equipment chamber to allow cooling to take place without any physical contact between the internal cabinet atmosphere and the surroundings.

Air Conditioners, in effect the fitting of a refrigeration system to the electronics enclosure. This system can allow the internal cabinet temperature to be below the external ambient.

Solid State Coolers, such as Peltier devices can be used to cool electronic devices and systems, but they have a relatively poor coefficient of performance and are usually impractical on a large scale. Main uses in electronics at the present time are the cooling of laser communication dies.

Liquid Circulation Cooling, where liquid is circulated either around the system as a whole, or to key high heat dissipation components using pipes and ducts. This method can be highly effective due to the higher h and thermal mass associated with liquid circulation systems. Unfortunately such systems are usually only practicable in large or high cost systems ie. Traction, or microwave/laser communication systems.

Liquid Immersion Cooling. In this method all or part of the system is immersed in an insulating fluid (such as a fluorocarbon) allowing direct contact with the electronic components. The fluid may then either be pumped, refrigerated, or allowed to circulate by free convection in order to couple heat into and out of the liquid. Unfortunately the liquids used are extremely expensive and as such are only viable at the present time at the leading edge of electronics technology (ie. some large main frame computers eg. Cray, use this system).

5. THE CHALLENGES OF THE FUTURE

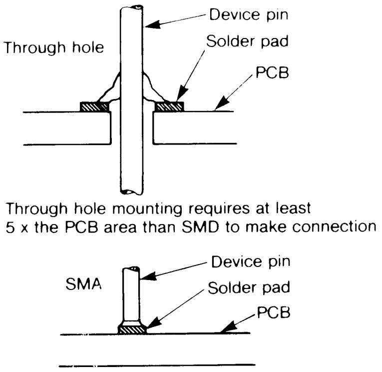
Perhaps the key phrase in the thermal management of electronics is "dissipation density" since it is only when the size of the package is small in comparison to the heat removal required that thermal management becomes a problem. Thus the challenges which face thermal management are principally those of miniaturisation. For many years the size of discrete components and systems alike have been largely controlled by the standard lead pitch of 2.54mm (0.1 inches), which in turn has been perpetuated due to the mechanical constraints of through hole mounting. However over the past 5 years the new technology of "Surface Mount Assembly" (SMA) has gradually percolated from both the high reliability military market (principally in the USA) and the volume consumer market (principally from Japan) into the professional electronics industry.

5.1 SMA a Challenge in Thermal Management

In conventional through hole mounted technologies the physical size of the components is more dependent on the mechanical constraints of the PCB, than on the silicon dies involved. Typically in through hole techniques a hole must be drilled through the PCB of sufficient size to accommodate leads, (and inter lead tolerances) and must then be surrounded by a copper land to allow soldering to the lead (see fig. 6). It is these requirements which lead to the 2.54mm standard for device lead pitch. In SMA however no through holes are required and thus the inter lead pitch may be greatly reduced, leading to

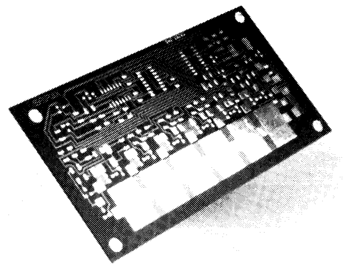
devices which are often 30% (and less) the size of their through hole counterparts. Unfortunately however the heat dissipation requirements remain the same since SMA is a packaging technology only and does not affect the silicon die at all.
As has already been seen the main factor in thermal management is the surface area of the structure (assembled device and any heatsink). Thus if the heat dissipation of the SMA component is to be identical then the heatsink requirement has to be identical. However to fit a heatsink which may be 20-30 times the volume of an SMA component clearly negates the miniaturisation advantages of SMA, for this reason much effort is being expended on the cooling of SMA's. One of the most promising methods of cooling SMA's is via the PCB substrate material using high thermal conductivity substrates such as Redpoint CLEApi (see fig. 7). This type of substrate can allow quite high power levels to be coped with, as well as to even out temperature distributions on the PCB brought about by components with vastly differing dissipations, for further details see reference 6.

Fig. 6 Comparison of size of through-hole versus surface-mounted device PCB contact area



Through hole mounting requires at least 5 x the PCB area than SMD to make connection

Fig. 7 Aluminium based PCB circuit for high-power surface-mount applications (Courtesy of Salplex Ltd.)



5.2 Packaging of Power Devices

The management of heat in semiconductor packages has for a long time been the sole preserve of the large semiconductor manufacturers. Recently some of the packaging and semiconductor design options have become available to end users via custom and semi-custom IC's (ASIC's). This Application Specific device is now becoming available in the power semi-conductor area with several companies offering custom and semi-custom power hybrids (see fig. 8). There are some new materials becoming available for applications in this custom packaging area, most of which are in the ceramics area for providing electrical insulation between the chip and the package whilst maintaining maximum thermal conductivity. Such substrates include Redpoint's Curamik material (see fig. 9), Aluminium Nitride, Beryllia[1], and Silicon Carbide.

Fig. 8 Example of a power hybrid design in which the power chips are mounted on ceramic-based composite substrate which provides electrical insulation whilst maintaining maximum thermal conductivity (Courtesy of General Hybrid Ltd.)

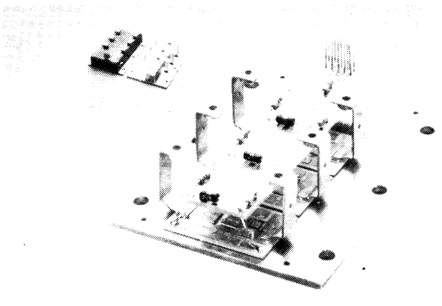
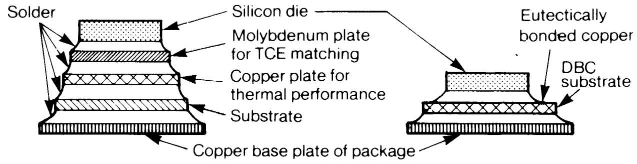


Fig. 9 Comparison of mounting methods for power chips showing simplification possible by using a ceramic-based composition-material which provides electrical insulation together with maximum thermal conductivity, eg Curamik DBC



(a) "Pyramid" type power chip assembly (b) Curamik (DBC) type power chip assembly

Typical thermal resistance	
0.4 C/(W/sq.cm)	0.3 C/(W/sq. cm) for 0.635mm alumina 0.3mm copper

6. CONCLUSIONS

Unfortunately the space required to discuss the whole area of electronic thermal management would fill a book in its own right. Thus this section has been aimed at establishing some of the ground rules and pointing the reader in the right direction for future reading in more detailed areas. The study of thermal management is a true engineering discipline which is within the grasp of all engineers provided the correct physical and theoretical understanding of the phenomena is obtained.

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[1] There are currently certain health concerns over the use of Beryllia and it seems likely that it's use will reduce.