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HEATPIPE COOLING OF AVIONIC MODULES

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0 EXECUTIVE SUMMARY

This brief document has been prepared by the ASSC Packaging Working Group to provide information on the potential use of heat pipes for cooling avionic modules. It is based on published information, not on practical tests.

The document reviews current methods used for avionic cooling and contains a digest of published information available on the capabilities of heat pipes in an avionic context. Risk areas and costs associated with heat pipes are described.

It concludes that heat pipes may have potential for cooling modules dissipating 80-200W, but warns that relatively little is known of their performance in the avionics environment, and recommends that practical work is necessary to address the following issues:

Orientation and acceleration problems
Vibration
Manufacturing techniques for avionic modules.

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GLOSSARY

ASAAC	Allied Standard Avionics Architecture Council
ASSC	Avionic Systems Standardisation Committee
EUCLID	EUropean Cooperation for the Long term In Defence
PC	Personal Computer
SEM-E	Standard Electronic Module, format E

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1 INTRODUCTION

The ASSC Packaging Working Group has been reviewing the status of heat pipes as a method of cooling modular avionics. This paper summarises the information obtained and identifies the areas where practical work is required.

2 BACKGROUND

Cooling is a major driver for the packaging of modular avionics. With the current generation of microprocessors dissipating tens of watts, and multi-chip module packaging allowing several of these to be fitted on a single avionics module, the total module heat dissipation may exceed 100W.

The ASAAC programme (ref.1) proposed two different cooling strategies; conduction cooling and liquid flow through:

2.1 Conduction cooling

In the case of conduction cooling, heat is transferred from the components on the module by conduction via a central heat plane in the module. This heat plane is clamped tightly to guide ribs on the avionic rack with wedge locks, allowing heat transfer to the rack. The rack is cooled by air (or liquid) flowing through chambers in the top and bottom. It has been calculated that this cooling method can be used for dissipations of up to 60W for a 233mm x 150mm x 20mm ASAAC-A module, perhaps slightly higher if advanced materials are used for the module.

Conduction cooling allows a simple, robust interface, but is unable to cope with the high power densities that are possible with multi-chip module packaging. A decision must be made to either trade off some performance for lower power consumption (as is the case for portable vs desktop PCs) or adopt a superior cooling technique.

2.2 Liquid flow through cooling

The liquid flow through cooling option relies on a liquid coolant flowing into the module via 'drip free' connectors. The liquid flows through the module via a hollow central heat plane, then out through a second coolant connector. The liquid flow through option is intended to cater for module dissipations up to 250W for ASAAC-A, with further extension to 500W being possible.

Liquid flow through cooling can cope with almost any requirement, but the liquid coolant can cause serious contamination, reliability and maintenance problems.

Heat pipes offer a means of increasing the performance of a standard conduction cooled module to the levels presently achieved by liquid flow through without the problems associated with taking liquid on and off a module.

3 HEAT PIPE CAPABILITIES

A heat pipe consists of a hermetically sealed tube containing a working fluid (typically ammonia, methanol or water) in both liquid and vapour form. The inside of the tube contains a structure (e.g. grooves in the pipe wall or a metallic screen wick) which allows the fluid to move along the tube by capillary action. When a section of the pipe is heated, the fluid in that section evaporates and travels along the tube. When the vapour reaches a cooler section it condenses, releasing its latent heat of vaporisation. The condensed liquid is transported back to the hot section of the pipe by capillary action and the process is repeated.

Within its working temperature range (determined by the working fluid and the pressure in the pipe), the performance of a heat pipe is considerably better than solid aluminium or copper. A particular advantage is the ability to eliminate the 'hot spots' beneath individual components which are the limiting factors for conventional conduction cooling.

figure

Figure 1 Temperature rise comparison

Based on a maximum heat flux of 20W/cm^2 (ref.2) through the 20cm^2 conduction cooling interface on an ASAAC-A module, it should be possible to cope with module dissipations of up to 400W.

4 PROBLEM AREAS

Heat pipes for avionic applications are perceived to have a number of problem areas, some real, some through a lack of practical research.

4.1 Orientation

A conventional heat pipe will not work efficiently if the evaporator (hot end) is higher than the condenser (cold end). The capillary action is not sufficiently powerful to overcome gravity and performance rapidly falls to near zero. Fortunately, performance is greatly enhanced (doubled) if the evaporator is below the condenser as gravity then aids the capillary flow.

figure

Figure 2 Effect of Heat Pipe Orientation on longitudinally grooved heat pipe (from ref.2)

This problem has long been thought to limit the applications of heat pipes to fixed platforms or space applications. European papers (e.g. ref.2) generally propose the use of micro pumps to move fluid about the heat pipe so as to counter orientation and acceleration. A simpler solution is to run a single heat pipe all the way across a module, positioning the evaporator in the centre and condensers at each end. If the pipe is oriented vertically one condenser floods and does not work efficiently but the other condenser has its performance enhanced, so there is little change in overall performance at the module level. This approach has been tried out in the US and good performance has been demonstrated under a realistic range of 'g' and orientation.

figure

Figure 3 **Condensers cooled via conduction to module guide ribs**

As far as the rack is concerned, if the modules are mounted vertically only one conduction interface to the rack will be fully utilised, leading to uneven heat loads on the rack coolant and some loss in performance. However, it should still be possible to achieve far better performance than simple conduction cooling.

4.2 Vibration

The vibration characteristics of heat pipes are largely unknown outside the US, where tests on the "double ended" heat pipes described above have demonstrated good vibration immunity at realistic aircraft levels. It is not known what the factors affecting the performance are.

4.3 Thermal expansion

The heat pipes commercially available are made from aluminium, stainless steel or copper. These materials all have thermal expansion problems - it is difficult to maintain a good contact between the heat pipe, the module frame and the substrate of a multi-chip module. The solution proposed (ref.3) is to embed the heat pipe in the central heat plane of the module, making it from the same material (e.g. beryllium copper).

4.4 Cost

The complex internal structure of heat pipes makes a module relatively expensive to produce (£800 for the heat pipe components in a SEM-E size module has been quoted). This is significantly more than a conduction cooled module even if advanced materials are used. It is not known how much this figure can be reduced through greater production volumes and more integrated design.

5. CONCLUSIONS

Although heat pipes have been used for a long time (since the early 1960's), relatively little is known of their performance in the avionics environment. All the available information indicates that they can bridge the gap between relatively cheap conduction cooling and difficult to maintain liquid flow through.

A tentative order of preference for cooling method (with approximate module dissipations for ASAAC-A) would be:

Simple conduction cooling (<60W)
Conduction cooling with advanced materials (60-80W, maybe 100W?)
Heat pipes (80-200W, maybe 400W?)
Liquid flow through (80-250W, maybe 500W?)

A large amount of work was carried out on heat pipes in the US in the early 1980's, particularly by Hughes and McDonnell Douglas but interest seems to have waned. Once a liquid flow through interface is installed for one module in a rack there is little additional burden in putting this interface on all high dissipation modules, so the need for heat pipes is eliminated.

Within Europe (e.g. European ASAAC members and EUCLID RTP 4.1) there is considerable resistance to liquid flow through cooling, particularly where a module has a considerable number of easily contaminated fibre optic contacts. It is, however, recognised that module dissipations above the capabilities of simple conduction are probable. Recent work (particularly in Germany and most recently by Thomson CSF in France) has therefore placed much more emphasis on heat pipes.

In order to increase confidence in the technology, practical work is necessary addressing the following issues:

Orientation and acceleration problems
Vibration
Manufacturing techniques for avionic modules

6. REFERENCES

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