

## Description

## Background of the Invention

This invention relates generally to electronic modules and more particularly has reference to the use of a self-activated heat pipe for temperature control and automatic mechanical clamping of electronic modules.

The problem of thermal management becomes exceedingly difficult and complex in advanced avionics systems. Such systems typically include a large number of circuit cards mounted in racks or motherboards in a high density fashion, with each card itself containing a high density of electronic components. Power consumptions as high as 150 watts are common. A high efficiency heat removal scheme must be provided to keep the components at a temperature within the range of 20°-100 °C needed for proper operation.

Older avionics systems were air cooled. Arrays of heat conducting fins were provided in the interiors of the circuit card modules. Air coolant was forced across the fins through openings in the modules to extract heat therefrom. That approach had a number of disadvantages which made it undesirable for use in modern advanced avionics systems. A primary disadvantage was excessive power consumption.

Consequently, the industry has now turned to liquid cooled modules. Such systems typically circulate a liquid coolant through cavities formed in the interior of cold plates which support the circuit card racks. Means are provided for communicating heat from the circuit card components to the interface between the rack and the cold plate, which heat is then absorbed and removed by the liquid coolant flowing through the cold plate.

One technique for communicating heat from the components to the interface is to provide a heat pipe with the circuit cards which absorbs heat from the components. A mechanical clamp used to attach the cold end of the heat pipe to a portion of the rack in thermal communication with the cold plate. See, for example, U.S. Patent No. 4 366 526 entitled, "Heat-pipe Cooled Electronic Circuit Card" and U.S. Patent No. 4 330 812, entitled "Circuit Board Electronic Component Cooling Structure with Composite Spacer". However, the known heat pipe techniques have proved incapable of keeping the circuit components in the desired temperature range. The components become too hot because the heat flow rate is insufficient to handle the large amounts of heat being generated.

It is well known that the thermal resistance at an interface between two bodies is dependent upon the contact pressure along the interface. As contact pressure increases, thermal resistance decreases to allow greater amounts of heat to flow across the interface. One possible explanation for the deficient heat flow rate in the known cooling systems is that the mechanical

clamp connecting the heat pipe to the rack creates insufficient pressure at the pipe/rack interface to reduce the thermal resistance therealong. If that is the case, then means for increasing the contact pressure should provide the necessary heat flow rate and should overcome the problems which exists in the known systems.

Thermal switches have been designed to utilize the varying thermal pressure within an integral heat pipe to create a variable contact pressure between the heat pipe and a temperature regulated body. See, for example, U.S. Patent No. 3 957 107, entitled, "Thermal Switch". However, those devices have been limited to low heat applications because they produce a maximum contact pressure which is far below that needed for efficient heat removal in high heat applications such as advanced avionics systems. Although insufficient contact pressure can be compensated to some degree by highly polished surfaces along the thermal interface, that approach necessitates costly machining steps. Consequently, such devices have not been used in circuit card modules.

A further problem with the known heat pipe systems for cooling circuit card modules is that the heat flow rate remains fixed at the level used for heat removal during normal operation. That level is higher than needed during a warm-up operation. As a result, excessive heat is removed during warm-up and the circuit components are slow to reach normal operating temperatures. A need thus exists for means to provide a variable heat flow rate, i.e., a heat flow rate which is high during normal operation and which is automatically reduced during warm-up operation.

Advanced avionics systems also present problems of maintenance and reliability. Mechanical clamps are currently used to lock the circuit card modules into the rack. Because each module has its own clamps, the maintenance technician for an advanced avionics system must engage in a time consuming process of inspecting and securing great numbers of clamps. Missed clamps can produce system failure or damage. Special installation tools are usually needed to apply the high closure forces associated with the clamps. In addition to increased tooling and maintenance inventory costs, the use of such tools and clamps has frequently caused breakage of modules during routine maintenance and assembly procedures. Hence, it is readily apparent that a need exists for means to lock the modules into the rack without the use of mechanical clamps or installation tools.

## Summary of the Invention

The present invention overcomes the problems which exist in the prior art.

In the present invention, one or more heat pipes are built into circuit card modules and arranged for thermal communication with the electronic

components thereon. The varying internal pressure generated within the heat pipes as heat is absorbed thereby urges an extendable structure outwardly from the module into intimate surface-to-surface contact with a portion of the rack in thermal communication with the liquid cooled cold plate. The contact pressure increases as additional heat is absorbed by the pipes, reducing the thermal resistance across the contact interface and increasing the rate of heat transfer to the cold plate. The extendable structure is constructed and arranged to produce contact pressures capable of achieving a sufficiently low thermal resistance for efficient heat removal from high power, high density avionics modules.

During warm-up operations, the contact pressure remains relatively low because the heat pipes have yet to absorb significant amounts of heat. The resulting high thermal resistance traps heat in the components, causing rapid warm-up.

The modules are designed to initially fit loosely in the rack. As heat from the components is absorbed by the heat pipes, the extendable structure is urged into engagement with the rack under sufficient pressure to effectively lock the modules into the rack. No mechanical clamps are required.

The present invention thus overcomes the deficiencies of the prior art by providing higher contact pressure at the thermal interface, by achieving faster component warm-up from cold start conditions, and by providing a self-activated clamping mechanism which eliminates the need for mechanical clamps and installation tools.

According to the invention there is provided an electronic module for use in a mounting structure having a heat sink associated therewith comprising, a body supporting one or more electronic components, heat pipe means associated with said body and in thermal communication with said components for receiving heat therefrom, said heat pipe means containing a heat transfer fluid in a condensation/evaporation cycle for transporting heat from relatively high temperature areas to relatively low temperature areas, characterized in that extendable means are associated with said body for extension therefrom into variable pressure thermal contact with said heat sink for heat transfer thereto, said extendable means having expandable chamber means in fluid communication with said heat pipe means so that said extension and said variable pressure are controlled by fluid pressure within said heat pipe means.

Preferred features of the invention will be described with reference to the accompanying drawings, in which:

Fig. 1 is a perspective view of the electronic module of the present invention in a circuit card rack.

Fig. 2 is a fragmentary, perspective, cutaway view of one embodiment of the electronic module of the present invention.

Fig. 3 is a fragmentary, perspective, cutaway view of a portion of the module shown in Fig. 2.

Fig. 4 is a perspective view of another embodiment of the electronic module of the present invention.

Fig. 5 is a perspective view of a sub-assembly of the module shown in Fig. 4.

Fig. 6 is an exploded, fragmentary, perspective view of a portion of the structure shown in Fig. 5.

Fig. 7 is a sectional view taken along the line 7-7 in Fig. 5.

Fig. 8 is a graphical representation of the thermal characteristics of a typical module made in accordance with the present invention.

#### Detailed Description of the Preferred Embodiments

Referring to Fig. 1, an electronic module made in accordance with the present invention, indicated generally by the numeral 10, is shown partially inserted into a typical circuit card rack 12 for an advanced avionics system. The module 10 has a planar body 14 with tongue members 16 of generally rectangular cross section extending along the lateral edges. The tongue members 16 are constructed and arranged to be received within vertical grooves or guideways 18 formed in opposed interior surfaces 20 and 22 of the rack 12. Handles 24 provided at remote ends of the upper longitudinal edge of the module 10 facilitate insertion into and removal from the rack 12.

A circuit card 26 containing a plurality of electronic components 28 is mounted on one or both surfaces of the module body 14. Conventional electrical connectors (not shown), such as pin connectors, along the lower longitudinal edge of the module 10 provide electrical communication between the components 28 and a motherboard (not shown) lying along the floor of the rack 12, in a manner well known in the art.

An advanced avionics system typically includes a plurality of racks which are mounted in drawer-like fashion in a support frame forming part of the aircraft structure. Opposed outer side surfaces 30 and 32 of the rack 12 are provided with an array of horizontally extending tongues 34 of generally rectangular cross section which are received within corresponding grooves or guideways 36 formed in the opposed inner surfaces 38 and 40 of the support frame side members 42 and 44. A liquid coolant (indicated schematically by directional arrows 46 and 48) circulated through interior passageways 50 formed in the side members 42 and 44 causes the members 42 and 44 to function as cold plates which absorb heat from the module 10 and the rack 12.

It will be appreciated that the thermal path for communicating heat from the components 28 to the cold plates 42 and 44 includes the interfaces between the tongue members 16 and rack guideways 18 and the interfaces between the rack tongues 34 and the cold plate guideways 36. In prior systems, those interfaces were held together by clamps or bolts or by an interference fit. As a result, the surface-to-surface thermal contact resistance at the interfaces was in the range of

about 1.0-1.5 in 2°C/watt which did not afford a sufficiently high rate of heat flow to the cold plates to keep the electronic components at proper operating temperatures. The present invention provides a technique for increasing the contact pressure at the interface surfaces to a level sufficient to reduce the thermal interface resistance to about 0.4 in 2°C/watt or less, a three-fold improvement which affords an increased heat flow rate to the cold plates and resultant lower operating temperatures for the electronic components.

The foregoing thermal resistance figures for the present invention assume that the interface surfaces are prepared by routine machining operations. The thermal resistance can be reduced even farther with special surface preparations, such as polishing, in a manner well known in the art.

Specific techniques for implementing the present invention at the module/rack interface are described herein. However, the present invention is not limited to the module/rack interface. It will be readily appreciated by persons skilled in the art that the techniques expressly described herein are equally applicable to the rack/cold plate interface. The present invention contemplates all such applications.

Figs. 2 and 3 show a simple embodiment which best illustrates the principles of the present invention.

The module 10' is similar to the module 10 shown in Fig. 1. It includes a planar body 14' having tongue members 16' of generally rectangular cross section along the lateral edges. Circuit cards 26' containing a plurality of electronic components 28' are mounted on both sides of the body 14'. For simplicity, the handles and the electrical connectors are not shown.

A plurality of heat pipes 52 extend longitudinally through the interior of the body 14'. The pipes 52 have a conventional structure which includes a conduit 54, preferably made of stainless steel, lined with a wick material 56. A working fluid, preferably Freon 12 or Freon 25, in the conduit 54 passes through an evaporation/condensation cycle to transport heat in a manner well known in the art. Specifically, heat is carried from a location where heat is applied, e.g., the electronic components 28', to a location where heat is removed, e.g., a surface in thermal communication with the cold plates 42 and 44. As heat from the components 28' enters the heat pipes 52, the small amount of working fluid confined in the wick material 56 in a liquid state is boiled. The resulting vapor migrates through the hollow interiors of the conduits 54 toward a location in thermal communication with the plates 42 and 44. Upon contact with the cool surface, the vapor condenses and returns to the location where heat was applied by a mechanism known as capillary pumping. The cycle continues and is self-propagating as long as heat is applied.

The present invention is not directed to heat pipe technology per se. The functional description

contained in the preceding paragraph is well known in the art. It will be readily appreciated that the present invention lies in applying heat pipe technology in a new and unobvious way.

Referring to Fig. 3, it can be seen that the conduits 54 terminate in chambers 58 formed throughout the interior of the tongue member 16'. The wick material 56 extends from the conduits 54 and lines the walls of the chamber 58.

Openings 60 are formed at spaced locations along one surface of the tongue member 16'. The number of openings can be varied as desired, but the preferred number is 6. Flexible bellows 62, preferably formed of stainless steel, are welded to the tongue member 16' above each of the openings 60. The bellows 62 have open lower ends to permit the interiors of the bellows 62 to be in communication with the interiors of the chambers 58. The wick material 56 extends through the openings 60 and lines the interiors of the bellows 62. As best shown in Figs. 2 and 3, the bellows 62 terminate outwardly at an interface sheet 64 which extends along the tongue member 16' and is welded to the closed outward ends of the bellows 62.

Although the preceding descriptions and illustrations of the chambers 58, bellows 62 and interface sheet 64 refer to only one lateral edge of the module 10', it is understood that the remote lateral edge of the module 10' is provided with similar structure.

The circuit cards 26' preferably have a base formed of a copper sheet which not only provides a flat surface for mounting the electronic components 28' but also provides a means for absorbing and evenly distributing heat from the components 28' to the heat pipes 52. The heat is then communicated longitudinally through the heat pipes 52 to the chambers 58 where it continues outwardly through the bellows 62 to the interface sheets 64 which, as shown in Fig. 1, are in thermal communication with the cold plates 42 and 44 through the rack 12.

As the temperature increases within the heat pipes 52, the internal saturation pressure of the working fluid also increases. The increasing fluid pressure expands the bellows 62 and urges the interface sheets 64 outwardly in a direction substantially normal to the plane of the module body 14'. Because the tongue/bellows/interface sheet assemblies 16', 62, 64 of the module 10' are received between opposed side walls 65 of the rack guiderails 18, extension of the interface sheets 64 from the body 14' urges both the interface sheets 64 and the opposite surfaces of the tongues 16' into contact with the side walls 65 of the guiderails 18 under increasing pressure. That pressure continues to increase as additional heat is received by the heat pipes 52. As the contact pressure increases, the thermal resistance at the contact interface decreases and allows more heat to flow from the heat pipes 52 to the rack 12 and ultimately to the cold plates 42 and 44. Heat is thus removed from the components 28' with greater efficiency, affording them a

lower operating temperature.

As mentioned above, it is desirable to obtain a thermal contact resistance of about 0.4 in-<sup>2</sup>/watt or less at the contact interface to keep the components in a high density, high power advanced avionics module at an operating temperature of about 20°-100 °C, preferably about 35°-70 °C. To achieve that resistance without highly polished surfaces at the contact interface, it is necessary to generate high pressure, typically 400-900 psi, within the heat pipes. The relationships between internal pressure and various heat pipe design parameters, such as length, diameter and spring rate of bellows, materials used for bellows, conduits and wicks, and the composition and quantity of the working fluid, are well within the skill of the ordinary artisan and thus can be varied as desired to suit particular needs while meeting the subject pressure requirements.

As mentioned above, the contact pressure at the module/rack interface is relatively low when heat is first supplied to the heat pipes 52 and gradually increases as additional heat is supplied. As a result, the thermal resistance at the interface is initially high and the heat tends to remain trapped in the module 10'. That phenomenon is advantageous in that it permits the electronic components 28' to warm-up rapidly from a cold start condition. As the components 28' reach normal operating temperatures, greater amounts of heat are communicated to the heat pipes 52, increasing the contact pressure and decreasing the thermal resistance at the interface to provide a high efficiency transfer of heat to the cold plates 42 and 44 which stabilizes the temperature of the components 28' within their normal operating range.

Fig. 8 shows a graph of temperature versus time for a test module 10' constructed as shown in Figs. 2 and 3. The module 10' was supplied with an input power of about 40 watts. The temperature in the heat pipe gradually rose from room temperature to about 120 °F in about 7 minutes and then stabilized at that temperature despite continuing input power. The temperature of the electronic components was slightly higher than the temperature of the heat pipe due to thermal losses but generally followed a similar pattern. The graph illustrates the rapid warm-up and the low thermal resistance at operating conditions made possible by the present invention.

In a preferred embodiment, the tongue/bellows interface sheet assemblies 16', 62, 64 are designed to be loosely received between the side walls 65 of the rack guiderails 18 when the interface sheets 64 are in a non-extended position, i.e., when the circuit card 26' is in a cold or non-operative condition. As a result, the module 10' can be easily inserted into the rack 12 without the need for applying high force to the module 10'. As the components 28' heat and cause extension of the interface sheets 64, the sheets 64 and the opposed surfaces of the tongues 16' are urged into contact with the side walls 65 of the guiderails 18 under increasing pressure. The pressure ulti-

mately reaches a level which is sufficient to snugly hold the module 10' in the rack 12 by frictional engagement alone. There is no need for clamps or bolts to keep the module 10' in place.

If necessary, the module 10' can be provided with a heat blanket, such as an inexpensive flat resistor, which is capable of generating heat when the electronic components 28' are in a quiescent state. That heat produces a sufficiently firm engagement between the module 10' and the rack 12 to ensure a good electrical connection between the module 10' and the motherboard for proper commencement of operation of the components 28' and also to ensure that the system will continue to operate properly even in an extremely cold environment such as might be encountered adjacent the exterior surfaces of an aircraft.

The problem of dirt tending to foul the electrical connections when the module 10' is held loosely in the rack 12 can be avoided by keeping the system in a sealed enclosure. Such enclosures are conventional for advanced avionics systems.

When the module 10' is intended for use in a system subject to intense vibration, it may be desirable to preload the bellows so that they attenuate input vibration and do not act as springs which would amplify vibration. Such preloading techniques are well within the skill of the art.

A preferred embodiment of the electronic module of the present invention, which is more amenable to mass manufacturing techniques, is shown in Figs. 4-7 and indicated generally by the reference number 10". The functional characteristics and advantages of the module 10" are substantially identical to those possessed by the module 10' described above and will thus not be discussed again in detail. The differences reside primarily in the details of structure and the following discussion will be directed to those differences.

Referring to Fig. 4, the module 10" includes a planar body 14" having tongue members 16" of generally rectangular cross section along the lateral edges. Circuit cards 26" containing a plurality of electronic components 28" are mounted on one or both faces of the body 14". Handles 24" are provided at the ends of the upper longitudinal edge of the body 14" to facilitate insertion and removal from the rack 12. A plurality of conventional pin connectors 66 are provided along the lower longitudinal edge of the body 14" and are electrically connected to the circuit card 26" to provide electrical communication between the electronic components 28" and the motherboard (not shown) in the rack 12.

Openings 68 are formed at spaced locations along one face of the tongue members 16" at both lateral edges of the body 14". Extendable pillar assemblies 70, described below in detail, are mounted in chambers 72 formed in the tongues 16" and have portions which project through the openings 68 for engagement with the side walls 65 of the rack guiderails 18 to perform functions

similar to those performed by the interface sheets 64 associated with the module 10' of the prior embodiment.

Referring to Fig. 5, it can be seen that the body 14" is made up of a plurality of body segments 74 joined in side-by-side fashion by mating dovetails 76 and grooves 78 formed along opposed longitudinal edges of the segments 74. Each face of the assembly of body segments 74 has a recessed planar central area 80, 82 which receives a circuit card 26".

Details of the body segments 74 are shown in Figs. 6 and 7. Although the figures and related descriptions refer to only one end of the segments 74, it is understood that similar structure is provided at both ends of the segments 74.

Referring to Fig. 6, it can be seen that a plurality of heat pipes 84, preferably 6 in number, extend longitudinally through the body segments 74 and terminate at both ends in chambers 72 formed in the end portions of the segments 74 constituting the tongue members 16". For ease of manufacture, the body segments 74, preferably formed of aluminum alloy, are extruded with heat pipes conduits 86 formed longitudinally through the segments 74. The chambers 72 are formed by hogging out the interior of the ends of the segments 74. Wick material 88, preferably 0.020-0.030 stainless steel, lines the interior walls of the heat pipes 84 and the chambers 72. The extendable pillar assemblies 70 are inserted through the openings 68 and mounted in the chambers 72 by welding. The ends of the conduits 86 are sealed with plugs 90 to prevent escape of the working fluid, preferably pure ammonia.

Details of the extendable pillar assemblies 70 are best understood by reference to Figs. 6 and 7.

The lower surface of a circular cap 92, preferably formed of aluminum alloy, is connected to the upper surface of an L-section ring 94, preferably formed of stainless steel, by inertia welding. The upstanding portion 96 of the ring 94 extends through an opening 98 of larger radius formed in the center of the cap 92 and terminates flush with the outer surface of the cap 92. A cylindrical guide 100, preferably formed of stainless steel, is received in the hub 102 defined by the upstanding portion 96 of the ring 94 and attached thereto by a circumferential TIG weld 104. The upstanding cylindrical end 106 of a sealed, single coil bellows 108, preferably formed of stainless steel, is held between the guide 100 and the upstanding portion 96 of the ring 94 by an interference fit. A cylindrical pillar 114, preferably formed of stainless steel, is mounted on the rigid base 112 of the bellows 108 and extends upwardly therefrom to be slidably received within the guide 100.

When a pillar assembly 70 is inserted through an opening 68 in a body segment 74, the bellows 108 and pillar 114 enter the chamber 72 and the lower surface of the cap 92 extending beyond the ring 94 comes to rest upon a lip 116 formed along the lower edge of the opening 68. The pillar assembly 70 is permanently connected to the body segment 74 by a circumferential electron

beam weld 118 between the cap 92 and the side wall of the opening 68.

Operation of the module 10" can now be readily understood.

Heat generated by the electronic components 28" is communicated through the conduit card 26" to the plurality of heat pipes 84 extending longitudinally through each of the interlocking segments 74 making up the body 14". Heat flows through the pipes 84 to the chambers 72 at the ends of the segments 74 and is then communicated to the pillars 114. As additional heat is received by the heat pipes 84, the internal saturation pressure of the working fluid increases. The pressure acts against the bellows 108 to urge the pillars 114 outwardly through the guides 100. The outward end surfaces 115 of the pillars 114, which are initially flush with the surface of the body 14", extend outwardly therefrom into pressure contact with the side walls 65 of the rack guiderails 18. As contact pressure between the pillars 114 and the guiderails 18 increases, the thermal resistance at the interface therebetween decreases to permit a high rate of heat flow from the pillars 114 to the cold plates 42 and 44. The modules 10", which are loosely received in the guiderails 18 when the end surfaces 115 of the pillars 114 are flush with the surface of the module body 14", become snugly locked into the rack 12 as the pillars 114 extend outwardly into high pressure frictional engagement with the side walls 65 of the guiderails 18. The variable contact pressure between the pillars 114 and the guiderails 18, ranging from low when heat is first applied to the heat pipes 84 to high after the pipes 84 have received a substantial amount of heat, produces an inverse variation in thermal resistance between the module 10" and the rack 12 which results in rapid warm-up characteristics of the type described with reference to the module 10' of the prior embodiment.

The upper and lower parts 120 and 122 of the flexible portion of the bellows 108 have mating wavelike shapes which substantially conform to the wavelike shape of the lower surfaces of the rings 94. As the bellows 108 contract under fluid pressure from the heat pipes 84, the mating surfaces 118, 120 and 122 engage each other to act as a mechanical limit or stop on the travel of the pillars 114. By proper design of the stopping action, the fluid pressures within the chambers 72 can be increased to the desired levels.

Although the invention has been described thus far solely in terms of its applicability to an electronic module, and more specifically to an electronic module for use in an advanced avionics system, it will be appreciated by persons skilled in the art that the invention is not limited thereto but can be used in a wide variety of applications requiring thermal management and/or self-actuated clamping. The scope of the invention should be construed to encompass all of those applications and embodiments.

While the invention has been described with reference to specific embodiments, the exact

nature and scope of the invention is defined in the following claims.

## Claims

1. An electronic module for use in a mounting structure (30, 32) having a heat sink (42, 44) associated therewith comprising:

a body (14', 14'') supporting one or more electronic components (28', 28'');

heat pipe means (52, 84) associated with said body and in thermal communication with said components for receiving heat therefrom;

said heat pipe means containing a heat transfer fluid in a condensation/evaporation cycle for transporting heat from relatively high temperature areas to relatively low temperature areas; characterised in that

extendable means (62, 70) are associated with said body for extension therefrom into variable pressure thermal contact with said heat sink for heat transfer thereto, said extendable means having expandable chamber means (62, 72) in fluid communication with said heat pipe means so that said extension and said variable pressure are controlled by fluid pressure within said heat pipe means.

2. An apparatus according to Claim 1, wherein the heat pipe means (52, 84) are located in an interior of the body (14', 14'').

3. An apparatus according to Claim 1 or 2, wherein the expandable chamber means comprise bellows (62, 108).

4. An apparatus according to any of Claims 1 to 3, wherein the body comprises a planar member (14', 14''), the extendable means (62, 70) being connected to the member for extension outwardly therefrom in a direction substantially normal to the plane of the member.

5. An apparatus according to Claim 4, wherein the heat pipe means comprise a plurality of heat pipes extending longitudinally across the member and the expandable chamber means comprise a plurality of bellows (62, 108) located adjacent lateral edges of the member.

6. An apparatus according to Claim 5, wherein the bellows (62) are connected to interface means (64) positioned along the lateral edge of the member for contact with said heat sink.

7. An apparatus according to any of Claims 1 to 6, wherein the expandable chamber means comprises cavity means (60, 72) formed in the body in fluid communication with the heat pipe means (52, 84) for receiving fluid pressure therefrom and bellows means (62, 108) closing the cavity means for moving with respect to the body in response to said fluid pressure.

8. An apparatus according to any of Claims 1 to 7, wherein the heat transfer fluid is selected from pure ammonia, Freon 12 and Freon 25.

9. An apparatus according to any of Claims 1 to 8, wherein copper sheets are interposed between the body and the components for transferring heat from the components to the heat pipe

means.

10. An apparatus according to any of Claims 1 to 9, wherein said fluid pressure is sufficient to obtain a thermal resistance of about 0.4 in<sup>2</sup>/C/watt or less at the thermal contact interface between the extendable chamber means and the heat sink.

11. An apparatus according to any of Claims 1 to 10, wherein the extendable means is constructed and arranged to provide said contact pressure in the range of about 400-900 psi.

12. An apparatus according to any of Claims 1 to 11, wherein heat transfer to the heat sink is sufficient to maintain the components at a temperature in the range of about 20°-100 °C when operating at an input power of up to about 150 watts.

13. An apparatus according to any of Claims 1 to 12, wherein the extendable means (62, 70) is constructed and arranged to provide a thermal contact interface with the heat sink (42, 44) having a thermal resistance which varies as a function of said fluid pressure within the heat pipe.

14. An apparatus according to any of Claims 1 to 13, further comprising means (118, 120, 122) for restricting travel of the bellows in a manner to increase fluid pressures therein.

15. An apparatus according to any of Claims 1 to 14, wherein the body (14'') comprises a plurality of interconnected segments (74), each segment being provided with independent heat pipe means (84).

16. An apparatus according to Claim 7, wherein upstanding pillar means (114) are connected to the bellows means (108).

17. An apparatus according to Claim 16, wherein the pillar means (114) is received within an opening (68) formed in the body (14'') when the extendable means is in a non-extended position.

18. An apparatus according to any of Claims 1 to 17, wherein the body (14', 14'') is constructed and arranged to fit loosely in the mounting structure (30, 32) when the extendable means (62, 70) is in a non-extended position, the extendable means and the heat sink being juxtaposed so that said contact pressure therebetween causes the body to fit snugly in the mounting structure when the extendable means is in an extended position.

19. An apparatus according to any of Claims 1 to 17, wherein mating pin connector means (66) are provided on the body (14'') and the mounting structure for providing electrical communication therebetween.

20. An apparatus according to Claim 4, wherein the expandable chamber means comprises bellows (62) located adjacent remote lateral edges of the member (14') which are connected to interface means (64) positioned along the respective lateral edges, said lateral edges and interface means being loosely received between opposed surfaces of guidrails (18) on the mounting structure (30, 32) when the extendable means is in a non-extended position, extension of the extendable means urging the interface means and the lateral

nature and scope of the invention is defined in the following claims.

## Claims

1. An electronic module for use in a mounting structure (30, 32) having a heat sink (42, 44) associated therewith comprising:

a body (14', 14'') supporting one or more electronic components (28', 28'');

heat pipe means (52, 84) associated with said body and in thermal communication with said components for receiving heat therefrom;

said heat pipe means containing a heat transfer fluid in a condensation/evaporation cycle for transporting heat from relatively high temperature areas to relatively low temperature areas; characterised in that

extendable means (62, 70) are associated with said body for extension therefrom into variable pressure thermal contact with said heat sink for heat transfer thereto, said extendable means having expandable chamber means (62, 72) in fluid communication with said heat pipe means so that said extension and said variable pressure are controlled by fluid pressure within said heat pipe means.

2. An apparatus according to Claim 1, wherein the heat pipe means (52, 84) are located in an interior of the body (14', 14'').

3. An apparatus according to Claim 1 or 2, wherein the expandable chamber means comprise bellows (62, 108).

4. An apparatus according to any of Claims 1 to 3, wherein the body comprises a planar member (14', 14''), the extendable means (62, 70) being connected to the member for extension outwardly therefrom in a direction substantially normal to the plane of the member.

5. An apparatus according to Claim 4, wherein the heat pipe means comprise a plurality of heat pipes extending longitudinally across the member and the expandable chamber means comprise a plurality of bellows (62, 108) located adjacent lateral edges of the member.

6. An apparatus according to Claim 5, wherein the bellows (62) are connected to interface means (64) positioned along the lateral edge of the member for contact with said heat sink.

7. An apparatus according to any of Claims 1 to 6, wherein the expandable chamber means comprises cavity means (60, 72) formed in the body in fluid communication with the heat pipe means (52, 84) for receiving fluid pressure therefrom and bellows means (62, 108) closing the cavity means for moving with respect to the body in response to said fluid pressure.

8. An apparatus according to any of Claims 1 to 7, wherein the heat transfer fluid is selected from pure ammonia, Freon 12 and Freon 25.

9. An apparatus according to any of Claims 1 to 8, wherein copper sheets are interposed between the body and the components for transferring heat from the components to the heat pipe

means.

10. An apparatus according to any of Claims 1 to 9, wherein said fluid pressure is sufficient to obtain a thermal resistance of about 0.4 in<sup>2</sup>°C/watt or less at the thermal contact interface between the extendable chamber means and the heat sink.

11. An apparatus according to any of Claims 1 to 10, wherein the extendable means is constructed and arranged to provide said contact pressure in the range of about 400-900 psi.

12. An apparatus according to any of Claims 1 to 11, wherein heat transfer to the heat sink is sufficient to maintain the components at a temperature in the range of about 20°-100 °C when operating at an input power of up to about 150 watts.

13. An apparatus according to any of Claims 1 to 12, wherein the extendable means (62, 70) is constructed and arranged to provide a thermal contact interface with the heat sink (42, 44) having a thermal resistance which varies as a function of said fluid pressure within the heat pipe.

14. An apparatus according to any of Claims 1 to 13, further comprising means (118, 120, 122) for restricting travel of the bellows in a manner to increase fluid pressures therein.

15. An apparatus according to any of Claims 1 to 14, wherein the body (14'') comprises a plurality of interconnected segments (74), each segment being provided with independent heat pipe means (84).

16. An apparatus according to Claim 7, wherein upstanding pillar means (114) are connected to the bellows means (108).

17. An apparatus according to Claim 16, wherein the pillar means (114) is received within an opening (68) formed in the body (14'') when the extendable means is in a non-extended position.

18. An apparatus according to any of Claims 1 to 17, wherein the body (14', 14'') is constructed and arranged to fit loosely in the mounting structure (30, 32) when the extendable means (62, 70) is in a non-extended position, the extendable means and the heat sink being juxtaposed so that said contact pressure therebetween causes the body to fit snugly in the mounting structure when the extendable means is in an extended position.

19. An apparatus according to any of Claims 1 to 17, wherein mating pin connector means (66) are provided on the body (14'') and the mounting structure for providing electrical communication therebetween.

20. An apparatus according to Claim 4, wherein the expandable chamber means comprises bellows (62) located adjacent remote lateral edges of the member (14') which are connected to interface means (64) positioned along the respective lateral edges, said lateral edges and interface means being loosely received between opposed surfaces of guiderails (18) on the mounting structure (30, 32) when the extendable means is in a non-extended position, extension of the extendable means urging the interface means and the lateral



edges into contact with said opposed surfaces under sufficient pressure to snugly hold the body in the mounting structure.

### Patentansprüche

1. Ein elektrischer Modul zur Verwendung in einer Befestigungsstruktur (30, 32), der eine mit ihr verbundene Wärmesenke aufweist (42, 44), mit:

einem Körper (14', 14'') der einen oder mehrere elektronische Komponenten (28', 28'') trägt;

einer Wärmerohrvorrichtung (52, 84), die mit dem Körper verbunden ist und in thermischem Kontakt mit den Komponenten ist, um Wärme von ihnen aufzunehmen;

wobei die Wärmerohrvorrichtungen eine Wärmeaustauschflüssigkeit in einem Kondensations/Verdampfungskreis beinhalten, um Wärme von Bereichen mit relativ hoher Temperatur zu Bereichen mit relativ niedriger Temperatur zu transportieren; dadurch gekennzeichnet, daß

Dehnungsvorrichtungen (62, 70) mit dem Körper verbunden sind, um sich von ihm fortzudehnen und in einem variablen Wärmedruckkontakt mit der Wärmesenke Wärme zu ihr zu transferieren, wobei die Dehnungsvorrichtungen ausdehnbare Kammervorrichtungen (62, 72) aufweisen, die in Flüssigkeitskontakt mit den Wärmerohrvorrichtungen stehen, so daß die Fortdehnung und der variable Druck durch den Flüssigkeitsdruck in den Wärmerohrvorrichtungen gesteuert wird.

2. Die Vorrichtung nach Anspruch 1, worin die Wärmerohrvorrichtungen (52, 84) in einem Innenteil des Körpers (14', 14'') angeordnet sind.

3. Die Vorrichtung nach Anspruch 1 oder 2, worin die ausdehnbaren Kammervorrichtungen Faltenbälge (62, 108) beinhalten.

4. Die Vorrichtung nach einem der Ansprüche 1 bis 3, worin der Körper ein ebenes Element (14', 14'') beinhaltet, wobei die Dehnungsvorrichtungen (62, 70) mit dem Element verbunden sind, um sich nach außen in einer Richtung, die im wesentlichen senkrecht zu der Ebene des Elementes ist, von ihm fortzudehnen.

5. Die Vorrichtung nach Anspruch 4, worin die Wärmerohrvorrichtungen eine Vielzahl von Wärmerohren beinhalten, die sich longitudinal über das Element und die ausdehnbaren Kammervorrichtungen erstrecken und eine Vielzahl von Faltenbalgen (62, 108) umfassen, die neben lateralen Ecken des Elementes angebracht sind.

6. Die Vorrichtung nach Anspruch 5, worin die Faltenbälge (62) mit Schnittstellenvorrichtungen (64) verbunden sind, die entlang der lateralen Ecke des Elementes zum Kontakt mit den Wärmerohren angeordnet sind.

7. Die Vorrichtung nach einem der Ansprüche 1 bis 6, worin die ausdehnbaren Kammervorrichtungen Hohlraumvorrichtungen (60, 72) beinhalten, die in dem Körper eingebracht sind und in Flüssigkeitskontakt mit den Wärmerohrvorrichtungen (52, 84) stehen, um Flüssigkeitsdruck von ihnen aufzunehmen, und Faltenbalgvorrichtungen

(62, 108) beinhalten, die die Hohlraumvorrichtungen verschließen, um in Abhängigkeit des Flüssigkeitsdruckes eine Bewegung im Verhältnis zum Körper zu ermöglichen.

8. Die Vorrichtung nach einem der Ansprüche 1 bis 7, worin die Wärmeaustauschflüssigkeit aus purem Ammoniak, Freon 12 und Freon 25 ausgewählt wurde.

9. Die Vorrichtung nach einem der Ansprüche 1 bis 8, worin Kupferbleche zwischen dem Körper und den Komponenten angeordnet sind, um Wärme von den Komponenten zu den Wärmerohrvorrichtungen zu transportieren.

10. Die Vorrichtung nach einem der Ansprüche 1 bis 9, worin der Flüssigkeitsdruck ausreichend ist, um einen Wärmewiderstand von ungefähr  $0,4 \text{ in}^2 \text{ } ^\circ\text{C/Watt}$  oder weniger an der thermischen Kontaktschnittstelle zwischen den ausdehnbaren Kammervorrichtungen und der Wärmesenke zu erhalten.

11. Die Vorrichtung nach einem der Ansprüche 1 bis 10, worin die Dehnungsvorrichtungen so konstruiert und angeordnet sind, um einem Kontaktdruck in dem Bereich von ungefähr 400-900 psi zu erhalten.

12. Die Vorrichtung nach einem der Ansprüche 1 bis 11, worin der Wärmetransport zu der Wärmesenke ausreichend ist, um die Komponenten bei einer Temperatur in dem Bereich von ungefähr  $20^\circ\text{C}$  bis  $100^\circ\text{C}$  zu halten, wenn sie bei einer Eingangsleistung von bis zu 150 Watt arbeiten.

13. Die Vorrichtung nach einem der Ansprüche 1 bis 12, worin die Dehnungsvorrichtungen (62, 70) so konstruiert und angeordnet sind, daß eine thermische Kontaktschnittstelle mit der Wärmesenke (42, 44) bereitgestellt wird, die einen thermischen Widerstand hat, der als eine Funktion des Flüssigkeitsdruckes in dem Wärmerohr variiert.

14. Die Vorrichtung nach einem der Ansprüche 1 bis 13, die ferner Vorrichtungen (118, 120, 122) beinhaltet, um die Bewegung der Faltenbälge in einer Art und Weise zu beschränken, so daß der Flüssigkeitsdruck in ihnen ansteigt.

15. Die Vorrichtung nach einem der Ansprüche 1 bis 14, worin der Körper (14'') eine Vielzahl von miteinander verbundenen Segmenten (74) beinhaltet, wobei für jedes Segment unabhängige Wärmerohrvorrichtungen (84) bereitgestellt werden.

16. Die Vorrichtung nach Anspruch 7, worin aufgerichtete Stützvorrichtungen (114) mit den Faltenbalgvorrichtungen (108) verbunden sind.

17. Die Vorrichtung nach Anspruch 16, worin die Stützvorrichtung (114) von einer in dem Körper (14'') eingebrachten Öffnung (68) aufgenommen wird, wenn die Dehnungsvorrichtungen sich in einer nicht gedehnten Position befinden.

18. Die Vorrichtung nach einem der Ansprüche 1 bis 17, worin der Körper (14', 14'') so konstruiert und angeordnet ist, daß er sich locker in die Befestigungsstruktur (30, 32) einfügt, wenn die Dehnungsvorrichtungen (62, 70) sich in einer nicht gedehnten Position befinden, wobei die Dehnungsvorrichtungen und die Wärmesenke nebeneinandergestellt sind, so daß der Kontakt-



druck zwischen ihnen den Körper veranlaßt, sich enganliegend in die Befestigungsstruktur einzufügen, wenn die Dehnungsvorrichtungen sich in einer ausgedehnten Position befinden.

19. Die Vorrichtung nach einem der Ansprüche 1 bis 17, worin zueinander passende Steckverbindungen (66) auf dem Körper (14") und der Befestigungsstruktur bereitgestellt werden, um eine elektrische Verbindung zwischen ihnen herzustellen.

20. Die Vorrichtung nach Anspruch 4, worin die ausdehnbaren Kammervorrichtungen Faltenbälge (62) beinhalten, die in der Nähe von entfernt liegenden lateralen Ecken des Elementes (14') angeordnet sind, die mit Schnittstellenvorrichtungen (64) verbunden sind, die entlang der jeweiligen lateralen Ecken angeordnet sind, wobei die lateralen Ecken und die Schnittstellenvorrichtungen lose zwischen gegenüberliegenden Oberflächen von Führungsschienen (18) auf der Befestigungsstruktur (30, 32) aufgenommen sind, wenn die Dehnungsvorrichtungen sich in einer nicht gedehnten Position befinden, wobei eine Dehnung der Dehnungsvorrichtungen die Schnittstellenvorrichtungen und die lateralen Ecken in einen Kontakt mit den gegenüberliegenden Oberflächen unter einem ausreichenden Druck zwingt, so daß der Körper enganliegend in der Befestigungsstruktur gehalten wird.

#### Revendications

1. Module électronique pour une utilisation dans une structure de montage (30, 32) associée à un radiateur (42, 44), comprenant :

un corps (14', 14") supportant un ou plusieurs composants électroniques (28', 28") ;

des moyens de caloduc (52, 84) associés à ce corps et en communication thermique avec lesdits composants pour recevoir la chaleur provenant dudit corps ;

les moyens de caloduc contenant un fluide de transfert thermique dans un cycle de condensation/évaporation pour le transport de chaleur de zones de température relativement élevée vers des zones de température relativement basse ; caractérisé en ce que :

des moyens extensibles (62, 70) associés à ce corps pour s'étendre à partir de celui-ci en contact thermique à pression variable avec le radiateur pour un transfert de chaleur vers ce dernier, les moyens extensibles comportant des moyens de chambre expansible (62, 72) en communication fluide avec les moyens de caloduc de sorte que l'extension et la pression variable sont commandées par la pression du fluide au sein des moyens de caloduc.

2. Dispositif selon la revendication 1, dans lequel les moyens de caloduc (52, 84) sont situés à l'intérieur du corps (14', 14").

3. Dispositif selon la revendication 1 ou 2, dans lequel les moyens de chambre expansible comprennent des soufflets (62, 108).

4. Dispositif selon l'une quelconque des reven-

dications 1 à 3, dans lequel le corps comprend une pièce plane (14', 14"), les moyens extensibles (62, 70) étant reliés à la pièce pour s'étendre vers l'extérieur de celle-ci dans une direction sensiblement normale au plan de la pièce.

5. Dispositif selon la revendication 4, dans lequel les moyens de caloduc comprennent plusieurs caloducs s'étendant longitudinalement à travers la pièce et les moyens de chambre expansible comprennent plusieurs soufflets (62, 108) situés au voisinage de bords latéraux de la pièce.

6. Dispositif selon la revendication 5, dans lequel les soufflets (62) sont reliés à des moyens d'interface (64) positionnés le long du bord latéral de la pièce pour être en contact avec le radiateur.

7. Dispositif selon l'une quelconque des revendications 1 à 6, dans lequel les moyens de chambre expansible comprennent des moyens de cavité (60, 72) formés dans le corps en communication fluide avec les moyens de caloduc (52, 84) pour recevoir de ce dernier une pression de fluide et des moyens de soufflet (62, 108) fermant les moyens de cavité pour se déplacer par rapport au corps en réponse à ladite pression de fluide.

8. Dispositif selon l'une quelconque des revendications 1 à 7, dans lequel le fluide de transfert thermique est choisi parmi l'ammoniac pur, le fréon 12 et le fréon 25.

9. Dispositif selon l'une quelconque des revendications 1 à 8, dans lequel des feuilles de cuivre sont interposées entre le corps et les composants pour transférer la chaleur issue des composants vers les moyens de caloduc.

10. Dispositif selon l'une quelconque des revendications 1 à 9, dans lequel la pression de fluide est suffisante pour obtenir une résistance thermique d'environ  $0,4 \text{ in}^2 \text{ } ^\circ\text{C}/\text{watt}$  ou moins à l'interface de contact thermique entre les moyens de chambre extensible et le radiateur.

11. Dispositif selon l'une quelconque des revendications 1 à 10, dans lequel les moyens extensibles sont réalisés et disposés pour fournir la pression de contact dans la gamme d'environ 400-900 psi.

12. Dispositif selon l'une quelconque des revendications 1 à 11, dans lequel le transfert de chaleur vers le radiateur est suffisant pour maintenir les composants à une température dans la gamme d'environ  $20^\circ\text{C}$ - $100^\circ\text{C}$  dans un fonctionnement avec une puissance d'entrée jusqu'à environ 150 watts.

13. Dispositif selon l'une quelconque des revendications 1 à 12, dans lequel les moyens extensibles (62, 70) sont réalisés et disposés pour fournir un interface de contact thermique avec le radiateur (42, 44) présentant une résistance thermique qui varie en fonction avec la pression de fluide au sein du caloduc.

14. Dispositif selon l'une quelconque des revendications 1 à 13, comprenant en outre des moyens (118, 120, 122) pour restreindre la course des soufflets de façon à accroître dans ceux-ci les pressions de fluide.

15. Dispositif selon l'une quelconque des revendications 1 à 14, dans lequel le corps (14")



comprend plusieurs segments interconnectés (74), chaque segment étant équipé de moyens de calodépendants (84).

16. Dispositif selon la revendication 7, dans lequel des moyens de colonne droits (114) sont reliés aux moyens de soufflet (108).

17. Dispositif selon la revendication 16, dans lequel les moyens de colonne (114) sont reçus au sein d'une ouverture (68) formée dans le corps (14") lorsque les moyens extensibles sont dans une position non étendue.

18. Dispositif selon l'une quelconque des revendications 1 à 17, dans lequel le corps (14', 14") est réalisé et disposé pour s'insérer de façon amovible dans la structure de montage (30, 32) lorsque les moyens extensibles (62, 70) sont dans une position non étendue, les moyens extensibles et le radiateur étant juxtaposés de sorte que la pression de contact entre eux provoque un ajustage en frottement doux du corps dans la structure de montage lorsque les moyens extensibles sont dans une position étendue.

19. Dispositif selon l'une quelconque des revendications 1 à 17, dans lequel des moyens de connecteur à broche d'accouplement (66) sont prévus sur le corps (14") et la structure de montage pour fournir entre ces derniers une communication électrique.

20. Dispositif selon la revendication 4, dans lequel les moyens de chambre expansible comprennent des soufflets (62) situés au voisinage de bords latéraux éloignés de la pièce (14') qui sont reliés à des moyens d'interface (64) positionnés le long des bords latéraux respectifs, lesdits bords latéraux et moyens d'interface étant reçus de façon amovible entre des surfaces opposées de rails de guidage (18) sur la structure de montage (30, 32) lorsque les moyens extensibles dans une position non étendue, l'extension des moyens extensibles poussant les moyens d'interface et les bords latéraux en contact avec les surfaces opposées sous une pression suffisante pour tenir doucement le corps dans la structure de montage.

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