Passive Heat Transfer Devices Respond to Satellite Application Demands

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The power and functionality demanded of today's military satellites is likely to become the standard in commercial applications in the near future.

Dissipation of the heat generated by increasingly powerful satellite electronics presents inherent challenges. Today's satellite applications, especially in the military sector, demand increasingly powerful functionality and a wider variety of electronics, which must be accommodated within a limited space. The drawback of increasing the number and power of electronics components is the generation of increasing amounts of heat while the available exterior surface area of the satellite —— through which the heat is rejected to space —— remains constant at best. Satellite designers and engineers rarely if ever have the luxury of increasing the exterior surface area of a satellite to improve heat rejection; and in many cases, any such increases would quickly be overtaken by increasing heat created by next generation electronics. As heat increases, the thermal devices used to dissipate the heat must transfer the heat effectively in any orientation and in the absence of gravity. Finally, satellite thermal solutions must operate under conditions in which maintenance and repairs are not possible, making flawless reliability a critical factor.

To meet these challenges, thermal engineers are turning to deployable radiators. These occupy minimal space on the satellite surface until deployment in orbit, to create increased surface area for heat dissipation. This offers the opportunity for more efficient electronics cooling, but the challenges of orientation, zero gravity and maintenance-free reliability remain. Fortunately, three reliable options are available: passive heat transfer devices such as loop heat pipes, axial grooved constant conductance heat pipes and encapsulated annealed pyrolytic graphite, APG. These three devices are used in concert to acquire, transport and reject the waste heat.

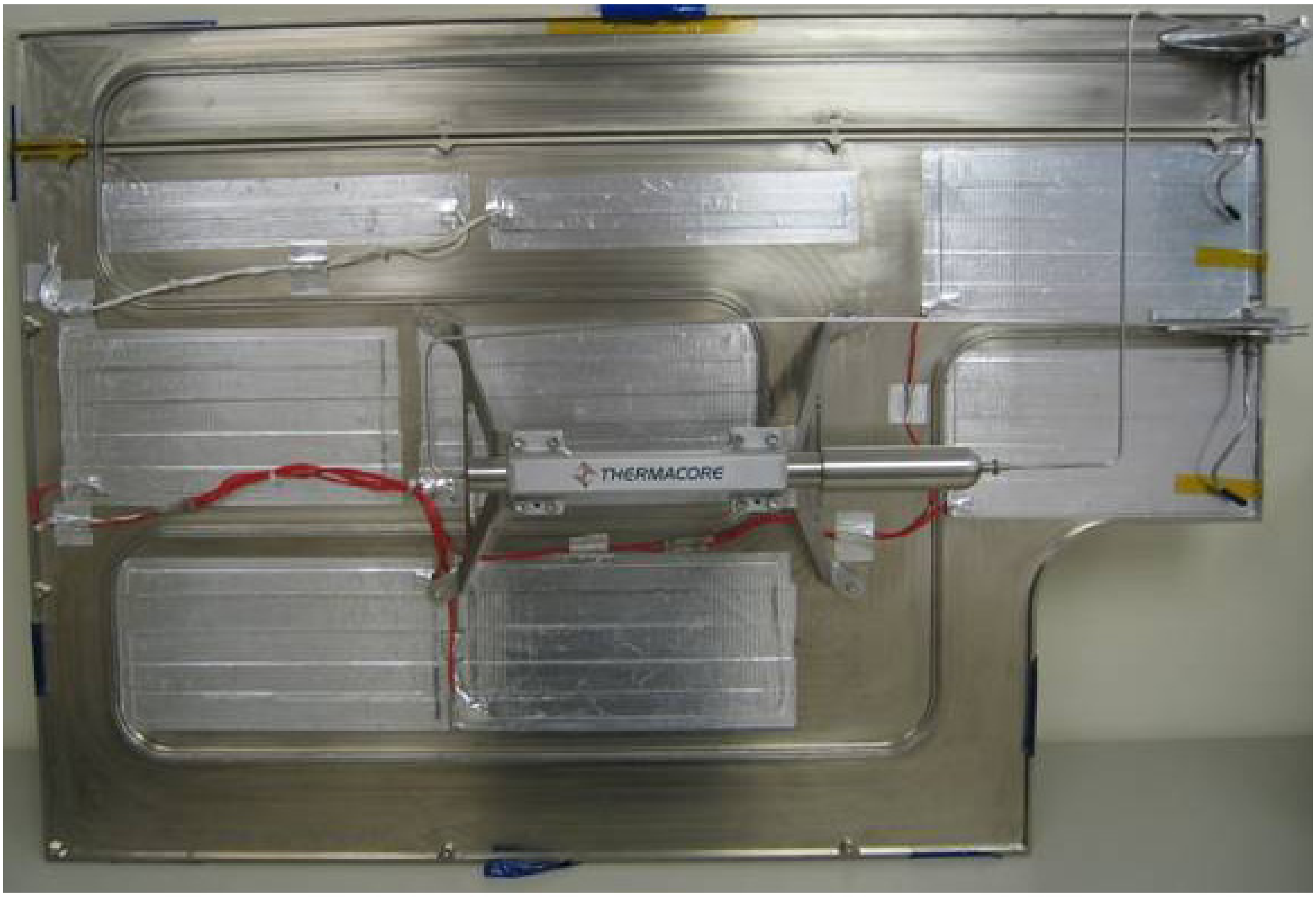
The advantages of heat pipes include flexible design capabilities to ensure reliable heat removal over long distances regardless of gravity.

Heat pipes in general, and loop heat pipes in particular, offer efficient heat transport with no moving parts to be maintained. These passive thermal devices can transfer heat over relatively long distances spanning several meters or more, and because they are completely passive and operate by two-phase heat transport (e.g., evaporation and condensation) rather than by active heat transfer mechanisms (mechanical pumped loops), they can transfer more heat with more reliability. The Loop heat pipes also operate in any orientation while exposed to gravity; this not only provides an advantage in space, it also helps make testing on earth more robust. Other thermal management solutions for example require the satellite to be rotated in odd orientations to accommodate the thermal system testing on earth.

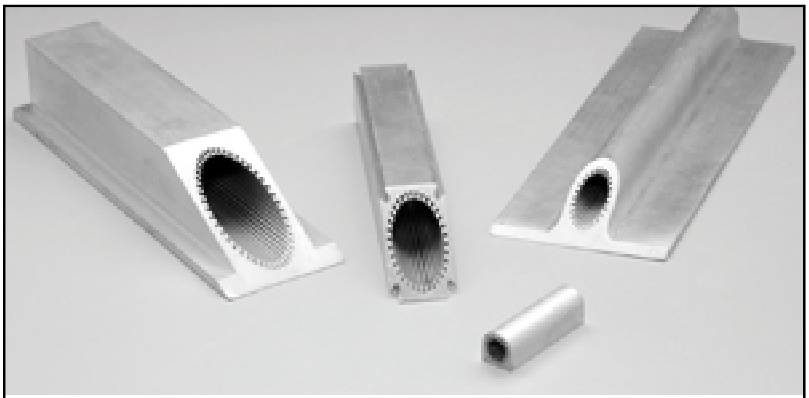
Typically, a heat pipe for space use is filled with a small quantity of working fluid; ammonia, ethane and propylene are typical fluids with ammonia being the most popular. Heat is absorbed by vaporizing the working fluid. The vapor transports the absorbed heat to the condenser region where the condensed vapor releases heat by radiation to space. The condensed working fluid is returned to the evaporator by capillary action in a wick structure.

Heat pipes can transfer heat more efficiently and evenly than solid conductors such as aluminum or copper because of their lower total thermal resistance and high effective thermal conductivity. Solid conductors such as aluminum, copper, graphite and diamond have thermal conductivities ranging from 250 W/m•K to 1,500 W/m•K compared with the broad conductivity range of heat pipes, which far exceeds these solid conductors. The latent heat of vaporization of a working fluid enables heat pipes to transfer heat from its source (evaporator) to the heat sink (condenser) over relatively long distances. Heat pipes typically have three sections: an evaporator section (heat input/source), adiabatic (or transport) section and a condenser section (heat output/sink). Their straightforward construction and lack of moving parts enable lightweight solutions such as a honeycomb-bonded radiator panels to be constructed integral with these thermal devices. The honeycomb provides the structural support while the heat pipes handle the heat transport and rejection.

Loop heat pipe thermal solutions are also bendable, flexible and routable. These properties, plus the availability of numerous proven-effective size and shape options (some of which are found throughout today's military aircraft), offer designers numerous viable choices in creating a thermal conduit to bring heat that is deep within the spacecraft and transport it to the exterior for rejection. Complimenting the loop heat pipe is axial grooved heat pipes and embedded annealed pyrolytic Graphite, APG. When used with a loop heat pipe, these devices gather or acquire the heat within the spacecraft and bring it to the loop heat pipes. The loop heat pipes become the workhorse that transports the heat to the deployed radiator panel.



Loop heat pipes extend the thermal performance of heat pipes over long distances and give designers considerable flexibility in creating thermal solutions for satellite applications.



Axially grooved constant conductance heat pipes (CCHPs) provide excellent thermal transfer of high heat over relatively long distances and can be more cost-effective than conventional heat pipes.

Axially grooved heat pipes use a circle of grooves in the interior wall of the heat pipe envelope as the capillary wick, maximizing the efficiency with which condensate is brought back to the evaporator from the cooler surfaces, where working fluid condenses. This design helps give axially grooved heat pipes greater distance transport than sintered powder metal or screen wick heat pipes. These thermal devices are sturdy but low in mass, helping to meet strict weight and size specifications for satellite applications.

A wide range of working fluids and envelope materials has been used successfully in axially grooved aluminum heat pipes to meet demanding thermal challenges. Proven working fluids with aluminum include ammonia, ethane, and propylene. The operating temperature range of the satellite sets the choice of working fluid to be used. For future high temperature applications where GaN electronics will be used, titanium with water as the working fluid is being developed.

The range of materials available for passive heat transfer, and the efficiency of thermal devices, has been further expanded by new advances, particularly the use of encapsulated annealed pyrolytic graphite (APG). APG is manufactured by decomposition of a hydrocarbon gas at high temperature in a vacuum furnace. This highly aligned crystalline graphite has an in-plane thermal conductivity of 1700 W/mK and is enclosed within an encapsulant such as aluminum or lightweight carbon fiber panel. APG-based thermal solutions offer effective thermal conductivity of 1000 W/m-K in many applications —— four times greater than that of solid aluminum and 2.5 times greater than that of solid copper. These thermal solutions can be made smaller, lighter and more efficient than traditional solid conductors using aluminum or copper. Vias can be added to maximize through-thickness heat conductivity or add structural support.

Thermal solutions using APG can also be matched to the coefficient of thermal expansion (CTE) of various microprocessors and directly attached to a semiconductor, further extending thermal capabilities within the spacecraft electronics boxes. Encapsulated APG is rugged, resistant to damage and, since it is a solid conductor it can perform effectively under significant loads. The use of APG-based thermal solutions is increasing in applications from surgical instruments to military aircraft and satellite applications.

The performance of passive heat transfer solutions, such as loop heat pipes, axial groove heat pipes and APG, appear to be the ideal response to the unique demands of satellite applications with state-of-the-art electronics. The expanded use of these thermal devices in concert will be needed, because the demands involved in cooling powerful aerospace electronics will increase for future satellite systems.