

COTS Cooling

ACI Technologies (ACI) is working on a project where one of the challenges is removing a large quantity of heat from audio amplifier circuits. This challenge is further complicated in that the heat generating circuits are located in a rack mounted box that needs to be shielded from electro-magnetic interference (EMI). Mechanically, this means that there cannot be open passages into the rack mounted box. We will first review the basic types of cooling available as commercial off-the-shelf (COTS) systems for the electronics industry, then discuss the pros and cons of each for different applications, and finally reveal the criteria and solution for the ACI project.

When working with circuitry and components requiring cooling in general, there are several options available for the dispersion of heat. Heat sinks, liquid cold plates, heat pipes, and thermoelectrics were trade studied within this project. Heat sinks are simply thermally conductive (typically aluminum) masses attached to heat generating electronic devices. The heat sink can be as basic as a block or it can be machined with fins to increase the surface area in contact with the surrounding air. Heat sinks can use natural convection or forced convection for cooling. Natural convection relies on the natural tendency for warm air to rise away from the heat sink to keep a constant stream of cool air crossing the unit. Forced convection employs the use of a fan to actively move air across the heat sink for cooling. Natural convection is a simpler solution that requires

no moving parts, so it is typically the preferred method of cooling. A major drawback to natural convection is that a device or assembly that generates a large amount of heat generally requires a large heat sink. If the design constraints of the product require a small overall package, a cooling fan will more than likely be required. The example in Figure 1 shows a forced convection heat sink with a fan blowing air between the fins for added cooling capacity.

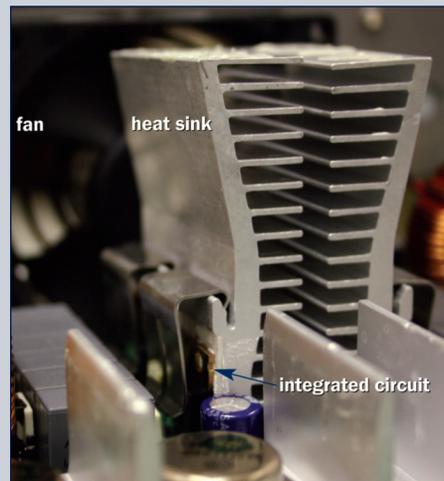


Figure 1: A forced convection heat sink with a fan blowing air between the fins for added cooling capacity.

Most electronic devices that convert power have at least one heat sink on them. The examples in Figure 2 show transistors connected to solid heat sinks. The unit on the top uses the aluminum plate in room temperature (25°C) air to dissipate the added heat. The unit on the bottom relies on connections to exterior aluminum plates to provide a thermal conduction path at temperatures close to 50°C.

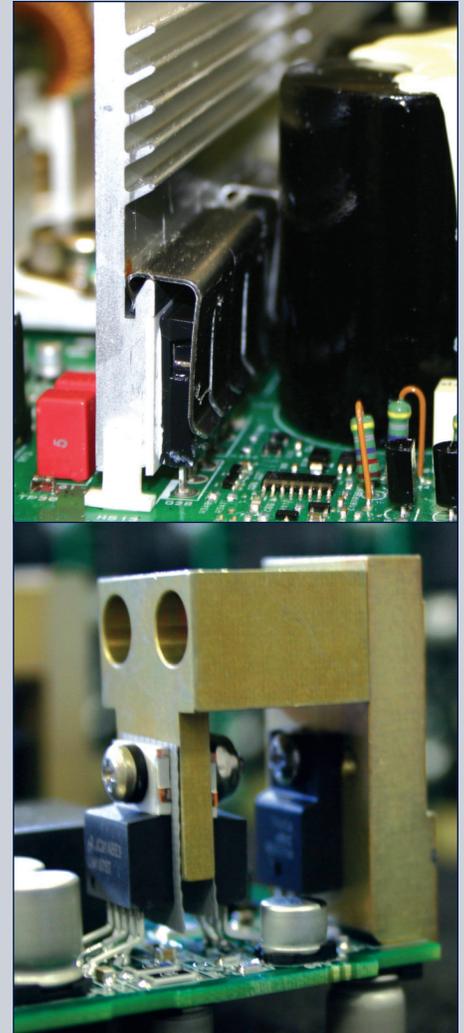


Figure 2: Transistors connected to solid heat sinks. The unit in the top photo uses the aluminum plate in room temperature (25°C) air to dissipate the added heat. The lower unit relies on connections to exterior aluminum plates to provide a thermal conduction path at temperatures close to 50°C.

connections to exterior aluminum plates to provide a thermal conduction path at temperatures close to 50°C. As a component generates more heat and the size of the heat sink cannot be increased, fins can be added to increase the surface area in contact with its surroundings.

Liquid cold plates are again thermally conductive masses, but they have passages that allow a coolant fluid to be pumped through them. Liquid cold plates allow the transfer of heat to a more remote location than heat sinks, which transfer heat to the immediately surrounding air. Figure 3 shows the detail of a typical cold plate system. The advantages of cold plates are that they can move large amounts of heat and that they can get the heat to a remote external location to be extracted. A drawback to a cold plate cooling system is that it requires a pump motor to move the fluid and a fan to assist in the heat exchanger in transferring the heat to the atmosphere. As usual, moving parts can create reliability concerns as well as adding the requirement for extra power consumption.

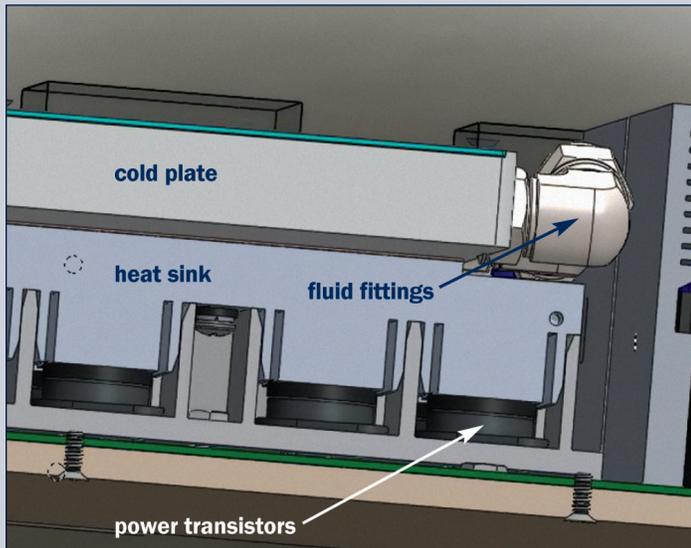


Figure 3: Detail of a typical cold plate system.

Heat pipes work using the physics of a closed loop evaporative system. This system allows the heat of the component to evaporate liquid (convert it to gas) at one end of the heat pipe, while the cool atmosphere at the other end removes heat from the gas. The liquid then condenses on the walls of the pipe and returns to the hot end, as shown in Figure 4. Most heat pipes contain capillaries, a screen mesh, or sintered powder on the inside of the tube walls to allow them to operate in any orientation. The ability of heat pipes to transfer heat in a closed system, while requiring no power, has made them very popular in the cooling of laptop computers.

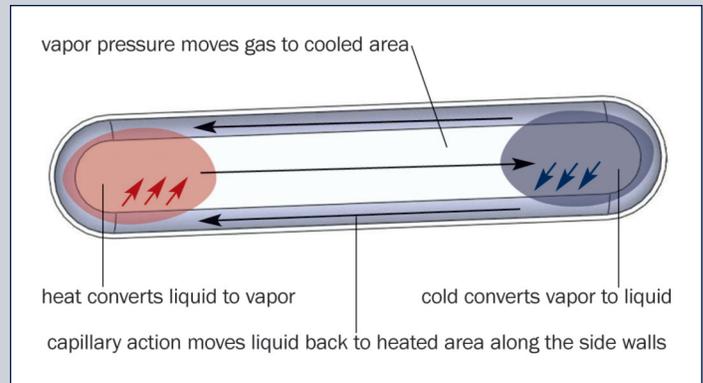


Figure 4: A heat pipe (cutaway view) is a simple device that can quickly transfer heat with almost no heat loss.

Thermoelectric cooling is based on the operating principles of the common diode. When electric current is applied across a semiconductor, it not only allows current to move but also allows heat to pass. The direction of the heat transfer can be controlled by the polarity of the voltage applied. A thermoelectric device is a group of “n” and “p” semiconductors connected in series to allow an active movement of heat under power. A thermoelectric cooling system cannot operate using a thermoelectric semiconductor alone. The thermoelectric device is used for its ability to force a temperature difference across its two surfaces. Typically, the thermoelectric is sandwiched between heat sinks or cold plates or a combination of the two. While thermoelectrics can force a large temperature differential over a small distance, one of the drawbacks to thermoelectric devices is the large amount of electrical power that is required to allow them to move heat. Typically, a thermoelectric device requires two watts of electrical power to move one watt of heat.

The project has stringent requirements from a physical and EMI perspective. The circuitry requirement dissipates over 300 watts of heat for each box during functional operation. The ambient temperature requirements for the project are -30°C to +60°C, and the maximum temperature of the transistor thermal plane is 80°C. The EMI concerns require a housing with no openings for air cooling. Another requirement was that four of these units need to be stacked on top of each other, so the large cooling surface area that may have been available on the top or bottom of the box could not be utilized. Available power is also a concern since the final system will be implemented in an aircraft.

A cold plate system was selected by a process of elimination based on these constraints. The constraint of EMI infiltration made a closed box the preferred housing, ruling out both natural and forced convection. The wide ambient temperature ranges and large amount



of heat eliminated heat pipes as a viable solution. In considering a thermoelectric system, a maximum power draw of twice the generated heat worked out to be 300 watts x 4 units x 2, or 2.4kW. This power draw induced ACI to turn to a cold plate system.

This choice allows the heat to be transported away from the transistors while maintaining a closed box design. The cold plate is attached to, but electrically isolated from, heat sinks that are attached to the transistors. The heat from the transistors rises through the heat sinks, passes through an electrically isolative thermal pad to the cold plate. The cooling fluid, which is pumped through the cold plate, takes the heat from the transistors and transfers it to a heat exchanger mounted away from the boxes. The heat exchanger transfers the heat from the fluid to the surrounding air while fluid at ambient temperature returns to the cold plate.

Testing for thermal qualification as well as qualification for multiple military specifications are the next steps for this project, however, all calculations of the design show that the cooling using COTS components will be successful.

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