Designing a Thermally Optimal Data Acquisition Unit

Read About

- Heat dissipation
- Flight test instrumentation (FTI)
- Data acquisition units (DAU)
- Remote nodes

Introduction

With the drive for data acquisition units (DAU) to have higher channel densities, be smaller and faster, and the trend towards distributed network architectures, thermal considerations are more important than ever and must be taken into account. Excessive heat can lead to malfunctions and/or shorten the lifespan of electronics. Some industrial, military, and aerospace applications face heat dissipation challenges that require careful mitigation strategies. For example, flight test instrumentation (FTI) is comprised of high performance data acquisition systems (DAS) that are required to operate reliably in harsh environmental conditions.

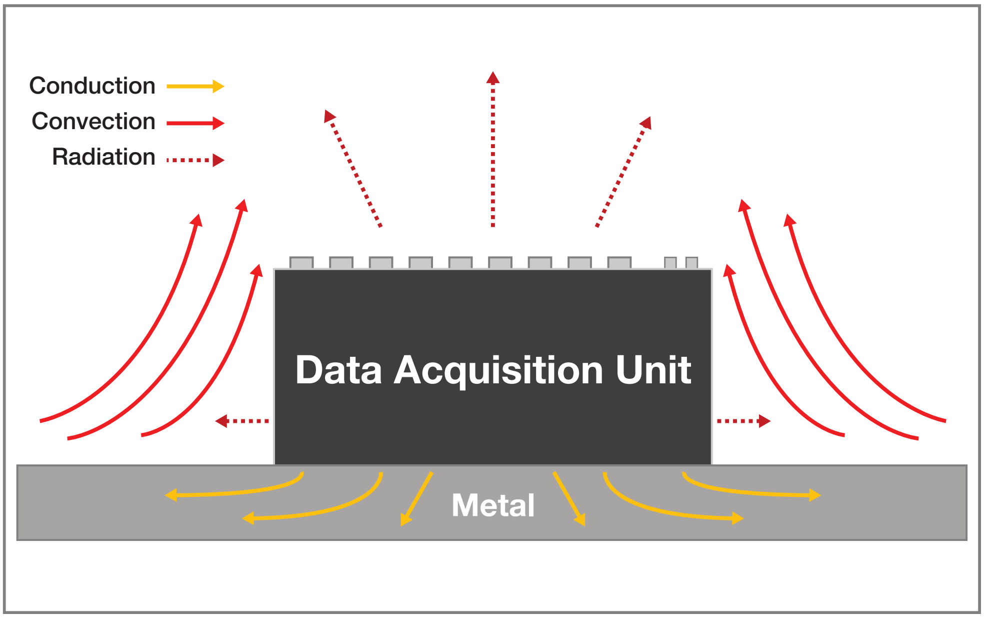


Figure 1: DAU heat dissipation is typically accomplished using conduction, convection, and radiation

Today, DASs use DAUs distributed throughout an aircraft, often in tight spaces, driving demand for smaller chassis. In parallel, the demand for higher performance from each DAU is on the rise, which increases the amount of heat generating components packed tighter together. Since chassis act as a heat sink for the components inside, a smaller chassis also means there is less metal to draw the heat away from the components.

This white paper examines DAU heat challenges including dissipation, and the best strategies to meet size and performance constraints without compromising data integrity with excessive heat build-up.

Hot Problems

All power-consuming devices generate heat due to the unavoidable internal loss of power because of their inefficiencies. Heat affects the way electronics perform; for example, as heat increases, so does electrical resistance. In order to properly understand the accuracy of a measurement, you need to know what the measurement accuracy is at the temperature the electronics are at. It is for this reason that electronics expected to perform in more extreme temperatures will be tested, and certified, over a range (typically -40 to 85°C for rugged aerospace electronics). This also means it's a good idea to check the details of accuracy claims by manufacturers as it's possible that a best case specification has been cited that may not match performance in realistic conditions.

Another effect of heat is that it ages hardware. Even if your systems are operating to a specification that meets your needs, if they are running hot, then their effective lifetime is reduced. It is approximately estimated that a 10°C increase halves the lifetime of the component (via Arrhenius equation). In reality, system failure is more complex than the lifetime of components, but it is still important especially when high temperatures are involved[i].This effective life should be factored into the investment as a low initial cost may be more costly in the long run if the item requires more frequent replacing.

Increasing Heat in Flight Test Instrumentation

The effects of heat on FTI is of greater concern today, and likely in the future, than in the past. This is due to the demand for increasingly compact systems, higher acquisition channel densities, and increased use of composite materials in aircraft construction.

Today's DAUs are distributed all around the aircraft, often in tight spaces that are not easy to access, which drives demand for smaller chassis. Since chassis act as a heat sink for the components inside, a smaller chassis means there is less metal to draw the heat away from the components. This is compounded by the desire for higher channel densities.

The amount of data engineers are looking to acquire is forever increasing, as is the capacity of modern electronics to increase performance in the same volume. This increase in throughput and channel count, which requires more power to be drawn into a chassis, which in turn means more heat is generated.

Another issue is that many aircraft now use composite materials in the airframe which are significantly less thermally conductive than metal. For example, the thermal conductivity (k) of fiberglass is ~ 0.04 vs 236 for aluminum[ii] (in SI units of watts per meter-kelvin (W·m–1·K–1) at 0°C). Thus, relying on conduction to remove heat from a chassis on a composite material may not be an effective strategy. These issues means a DAU unable to use one of the three main forms of heat dissipation, conduction (see "Heat Dissipation" below), as effectively as before because the lower the k value, the poorer the material is at conducting heat.

Table 1

Material	Heat Conduction (*k*)
Carbon steel	30-60
Stainless steel	15
Aluminum	263
Titanium	22
Glass	1

Table 1: Thermal conductivity of some common materials used in DAUs and aircraft

Heat Dissipation

There are three methods used to transfer or remove heat from power devices: conduction, convection, and radiant. In all cases, the heat is being transferred from the power device to another medium that is at a lower temperature because heat is constantly seeking to move to any object or medium that is cooler.

Conduction

Conduction is defined as the transfer of heat from one hot part to another cooler part by direct contact. For example, many DC-DC converters have a flat surface that is designed to mount directly to an external heat sink or cold plate that will conduct the heat away from the power device by direct contact, thereby cooling it. All power supplies, for example, use internal heatsinks to help conduct the heat away from the hot devices.

Similarly, a DAU can be cooled by attaching it to a conductive surface. Conduction is the most widely used method of heat transfer. Most high powered electronic components and systems use some type of heatsink to help conduct the heat away.

Convection

Convection involves the transfer of heat from a power device by the action of the natural fluid flow surrounding and contacting the device (air is a low density fluid). Another type of convection cooling requires forced-air-flow via fans or blowers across, or through, the unit. Some units use heat sinks (with or without forced air) to assist in transferring the heat away to cooler air.

Radiant

Radiant is the transfer of heat by means of electromagnetic radiation (energy waves) that flow from a hot object to a cooler object. True radiant heat transfer can take place in a vacuum and does not require air. All devices give off radiant heat; however, radiant heat transfer is less effective as a means to cool a power device than conduction or convection cooling. It's also notable that objects with a dark color also radiate heat better than light colored ones, although in practice this makes little difference to overall cooling.

Dissipating Heat in FTI Systems

Keeping components inside a DAU cool is, in theory, simple and easy. One just needs to ensure they make good thermal contact with the chassis, add a big heat sink and some fans to the chassis, and bolt the DAU to a big chunk of metal in a well ventilated location. However, this scenario is rarely practical, and while it does sometime happen that DAUs have large heat sinks and are located in large racks with forced air cooling, this is far less common and much less desirable than it used to be, and not an option for more compact aircraft.

Figure 2: Heatsinks are effective for removing heat but are often impractical for ultra-compact systems due to their size

Which heat dissipation methods are used in existing FTI systems generally depends on the age of the installation and the size of the aircraft. For example, older DAUs tend to be relatively large and bolted to metal in aircraft made of primarily metal. This allows for good conduction cooling from the DAU and, assuming a good design, from the components in the DAU to a larger metal chassis. There may also be some open space around them to also allow for decent convection cooling.

Some DAUs are placed in racks that have passive or forced air cooling (usually only an option in large aircraft). These benefit from good convection cooling as well as some conduction in the rack.

The trend towards smaller chassis located in tight spaces, sometimes on composite structures, makes it increasingly difficult to dissipate heat from the DAU components. It is therefore critical to properly understand and implement good thermal design decisions in DAUs to meet current and future FTI DAU requirements.

Optimal thermal design

Generally, DAU components are mounted on printed circuit boards (PCB) where there are several thermal design decisions that should be followed for optimal operation. The intricacies of this subject are significant on their own and outside the scope of this paper – more information is online[iii]. At a high level, it is important to ensure that heat can be quickly transferred away from components and that heat isn't concentrated in any one spot.

Flight test DAUs typically consist of a chassis and modules. It is important that there is a good method of moving the heat away from the modules to the chassis to help move heat away from components. In this way, the chassis itself acts as a heatsink. How effective this function is depends on a few factors such as how the chassis is constructed, how good the thermal contact is between the chassis and its modules, and how power is utilized in the chassis.

There are generally two methods of constructing chassis: using a solid chassis and separate modules, or using a 'slice of bread design'. A solid chassis has slots in which modules can be inserted, similar to inserting disk drives into a recorder. Another method of building chassis is to construct the chassis out of the acquisition cards themselves. Using this "slice of bread" method there is no separate chassis. The chassis is formed by connecting several acquisition cards together and securing them via some locking mechanism.

A solid chassis has the advantage of being a large piece of contiguous metal that allows heat to quickly flow from a hotter region to a cooler one. A disadvantage is that inserting and removing modules makes it difficult to create a perfect thermal contact between the modules and the chassis. A slice of bread approach has the advantage of being able to very tightly connect the PCB to the chassis, as the chassis is part of the module. The disadvantage of the slice of bread approach is that it is difficult to create a fully conductive seal between the modules.

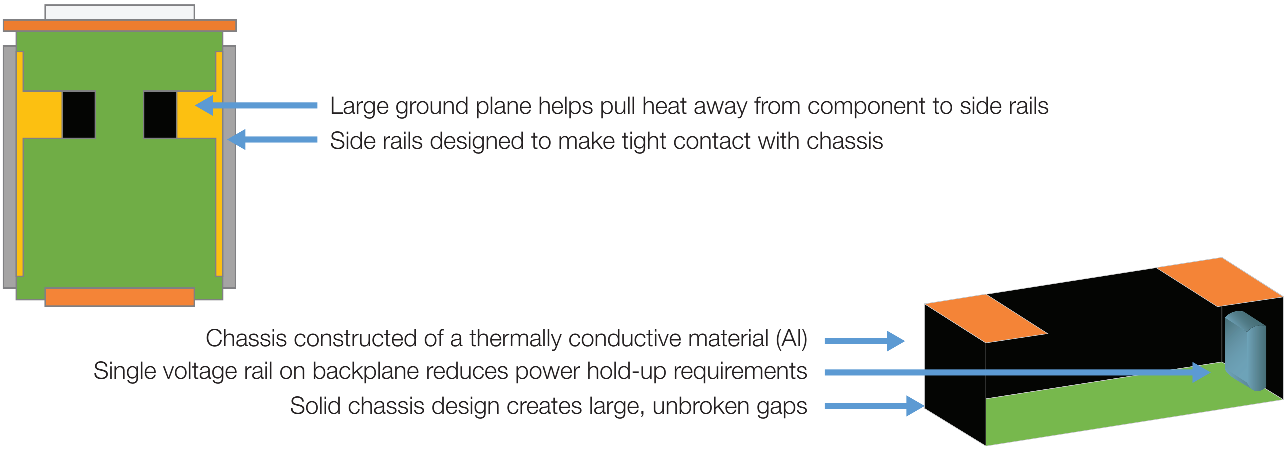
Whichever chassis design is chosen, it is likely constructed from metal - typically aluminum or steel. Steel is cheaper and stronger than aluminum so chassis walls can be a little thinner and material costs will be lower. However, aluminum appears a better choice as it is a significantly better heat conductor (k = 236 vs. 15), is lighter and easier to mill. In practice there is little cost saving for a finished steel chassis, any size difference is trivial and the much better thermal properties help move heat from the chassis into the surrounding environment.

There are also design decisions that can help a DAU better use power. It is common for DAUs to supply multiple voltages to modules as there are different voltage requirements for module operation, sensor excitation, and so on. To avoid data loss in the event of a black or brown out, power holdup capacitors are used in the power supply. Reducing the number of voltages the power supply provides, lowers the number of holdup capacitors required. This both reduces the power drawn, and thus heat generated, as well as the power supply size. Voltage conversion can instead be performed on the modules.

The Curtiss-Wright Approach

Curtiss-Wright has decades of experience designing compact, power and thermally efficient equipment. This experience was vital when designing the Axon family of DAUs as the rapidly increasing data acquisition requirements, coupled with the demand for smaller chassis, meant thermal constraints were a key design challenge. The following discussion outlines some of the decisions that were made to address these challenges.

Starting with the module design, a large ground plane is used to help draw heat away into the modules side rails. A dual side rail system closely couples the module to the chassis, while still allowing enough freedom to remove modules without damage. To best distribute heat from the modules around the chassis, a solid chassis milled from a single block of aluminum was chosen. This minimizes any gaps that could lead to hotspots and the excellent thermal properties of aluminum ensures heat is transferred away from the modules as quickly as possible without requiring more expensive or exotic materials. In this way the chassis acts like a heat sink attached to a microprocessor in a PC (which are commonly made from aluminum due to its excellent thermal properties).


Large ground plane helps pull heat away from component to side rails

Side rails designed to make tight contact with chassis

Chassis constructed of a thermally conductive material (Al)

Single voltage rail on backplane reduces power hold-up requirements

Solid chassis design creates large, unbroken gaps

Figure 3: The Axon's design maximizes thermal dissipation at each stage to keep the components cool enough without needing external heat sinks or forced air

Within the chassis, a single voltage rail is used which allows a single hold-up capacitor to be used, meaning less power is drawn to ensure the DAU can effectively deal with common supply voltage variances or interruptions.

Theoretically, the best chassis design to remove heat from a module would be a single slot chassis, maximizing surface area vs. volume and minimizing the number of heat producing components. While true for a traditional DAU, there is a limitation to how small you can make a DAU to house a single module; the chassis must also house a transmitter card (to send data via Ethernet, IRIG 106 chapter 4 PCM or IRIG-106 chapter 7) and a power supply.

The Axon DAUs backplane uses a serial point-to-point link for each module that provides data and power lines. This allows Axon to provide a unique solution for particularly tight or hot locations (such as wings or engine nacelles) – the Axonite. The Axonite chassis is simply houses a single module and is connected to an Axon chassis using a single wire that connects to the serial backplane. In essence, the module appears to the Axon chassis to be located within it, when in fact it can be located up to 10 meters away in a separate dedicated Axonite chassis (Figure 4).

A final indirect method used for effective thermal management is the use of thermal monitoring on all Axon DAUs. I^2C temperature sensors are integrated into all parts, including top blocks, on board modules, in PSUs etc. This provides insight into how hot elements are and can be used for troubleshooting or data integrity assurance purposes.

Keeping Tomorrow's DAUs Cool

Good designers give careful consideration to heat dissipation in any electronic system to help ensure it functions as expected and doesn't suffer a dramatic reduction in lifespan. This is even more important in applications such as FTI where the demands for more powerful and compact DAUs, coupled with the unique requirements of aerospace, present tough challenges.

Curtiss-Wright carefully considered these challenges when designing its Axon range ensuring the DAU family could meet the industry's current and future requirements for ultra-compact and powerful units. This exercise has proved successful and has resulted in a family of DAUs that are not only the most powerful for their size, but also capable of being deployed without the need for forced cooling or additional heatsinks.

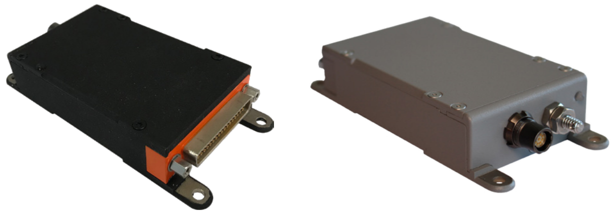


Figure 4: The Axonite allows an Axon module to be remotely located from the main chassis by 10 meters, making it ideal for tight or hot locations

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Products

- Axon - Ultra-Compact, Scalable and Reliable Data Acquisition
- Axonite - Remote Module Chassis

References

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[ii] Engineering ToolBox, (2003). Thermal Conductivity of common Materials and Gases, online, accessed 18/09/2019, available at: https://www.engineeringtoolbox.com/thermal-conductivity-d_429.html

[iii] Texas Instruments, 2013, “AN-2020 Thermal Design By Insight, Not Hindsight”, online, accessed September 2019, Available from http://www.ti.com/lit/an/snva419c/snva419c.pdf