TECHNOLOGY WHITE PAPER

Miniaturizing Space COTS for Small Launcher Applications

CURTISS-WRIGHT

DEFENSE SOLUTIONS

Read About

Space COTS

Radiation Tolerant Systems

Launchers

Space Vehicles

Small Launcher Applications

Introduction

The world of space flight has changed dramatically in the last decade. This change has been driven by the demand to lower the cost of deploying commercial satellite constellations with a large number of space assets to orbit and the advent of space tourism, which has in turn fueled the rise of private and commercially driven space vehicle development companies (e.g. SpaceX, Orbital Sciences, Blue Origin, Virgin Galatic, RocketLab, Firefly) and the growth of space programs in other countries such as China, India, and Japan. In addition, the commercial space companies and national space agencies such as NASA and ESA are seeking to cut costs and speed development by using commercial-off-the-shelf (COTS) equipment to meet the needs of future space missions.

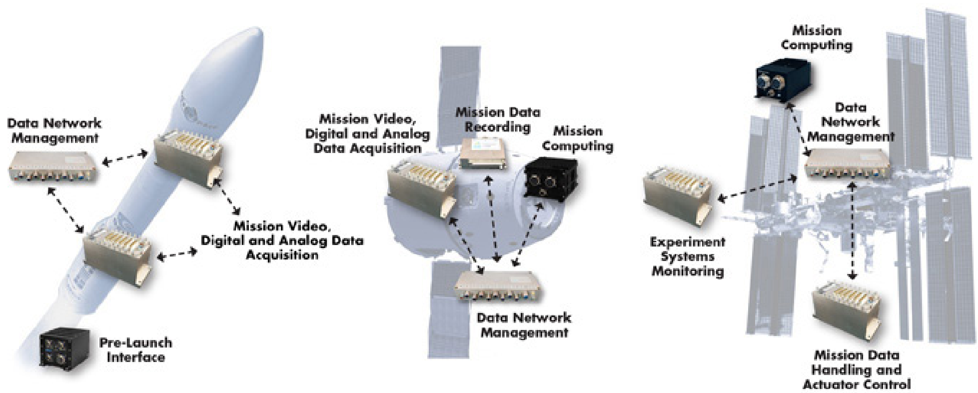


Figure 1: COTS equipment can be used in multiple space applications

These trends in the global space market have resulted in space companies and space agencies selecting and using equipment previously only validated in commercial and military flight-testing. Another trend is the move to using smaller launchers to keep costs down and increase the frequency of launches. This creates a challenge for Development Flight Instrumentation (DFI) and Operational Flight Instrumentation (OFI) as the same functionality is required, but the package must be smaller. This white paper discusses the need for, and challenge of, compact space COTS systems for modern space applications, in particular for small launcher applications.

Info

curtisswrightds.com

Email

ds@curtisswright.com

Moving to COTS

Increasing commercial pressures are putting focus on keeping costs to a minimum for space missions. This has led to a widespread use of COTS DFI and OFI for space launchers, and indeed vehicles. The problem is to mitigate against environmental and radiation effects while staying within the scope of limited program budgets and without compromising the overall mission assurance requirements. Not all COTS instrumentation is suitable for use in the environments encountered in space, and there must be careful consideration given to the risk of failure for COTS equipment used on-board spacecraft due to vibration, radiation exposure and the thermal environment of space, which may lead to a mission failure.

Launcher and Space Environment Concerns

The environment experienced by equipment located on a launcher is still very different from that experienced in terrestrial environments. So it is not sufficient to just take a system that has proven ruggedized performance in, for example, a military jet, and expect that it will operate effectively and reliably in a launch vehicle. For example, the environmental shock and vibration experienced by equipment during launch and the journey into orbit tends to be more extreme than that experienced by equipment during terrestrial flight with the added factor of operating in a vacuum during the later stages of the launch.

One important factor to consider when selecting COTS electronics for space applications is radiation exposure. A platform's orbit trajectory and the duration of its mission determine the amount of exposure to trapped radiation and to solar and cosmic radiation sources. The overall impact that this radiation has on the avionics hardware is determined by a complex interaction of shielding, circuit design, device technology, and particle energy spectra. That's why radiation tolerance is one of the key criteria when system integrators select the avionics for their spacecraft. For launcher applications, the risk to electronics posed by radiation is much lower than for spacecraft or satellite applications although it is still something that must be considered for mission critical electronics.

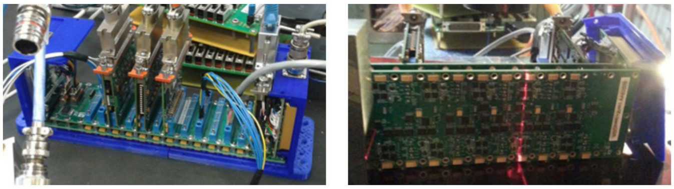


Figure 2: Extensive testing is required to prove systems are capable of functioning proper in radiated environments

There are other space vehicle requirements that present special challenges for COTS equipment. These include

- Expendable launch vehicles that require all data to be telemetered from the vehicle through all stages of the launch including blackout periods.
- Radical changes to the instrumentation topology during the mission, as sections of the vehicle detach, possibly carrying sub-sections of the instrumentation network with them.
- Large vehicles requiring data to be transferred over 50-100 m of cabling at high speeds.
- Instrumentation on orbiting vehicles may be "out of sight" of ground receiving stations for long periods of time, requiring the capability for on-board recording and transmission on demand.

These factors are given detailed consideration in another white paper (see Learn More section at the end of this document).

Shrinking Costs lead to Shrinking COTS

The market is evolving towards smaller launchers to reduce costs for launching the small satellites that typically make up the new commercial space based constellations. This means that everything onboard must also be smaller and lighter or you will lose valuable mass that could be assigned to the payload. Every kilo is valuable which means every gram spent on instrumentation, wiring or supporting systems is no longer available for payload.

For example, the Rocketlab Electron launch vehicle, one of the new breed of small launchers, has maximum payload of 225 kg to low earth orbit (LEO). Compare this to a larger launcher such as SpaceX's Falcon 9 which has a payload to LEO of 22,800 Kg. A 1 kg addition in DFI/OFI represents a 0.67% payload drop for the Electron and only 0.0044% for the Falcon 9.

Shrinking COTS electronics in principal is simple enough – one can just wait for electronics to shrink. Shrinking COTS while improving performance and ensuring flexible, rugged and robust operation in a space application environment is not. Modern data acquisition COTS systems use a chassis and modules to ensure lower cost, flexibility and configurability.

Flexibility is provided on the chassis level by designing each chassis to consist of multiple acquisition cards, with each acquisition card carrying out a different function. Further flexibility can be provided at the card level by allowing the behavior of the acquisition card to be configured. At the system level, an instrumentation engineer can create almost any configuration using a network of DAUs. Reliable and robust operation is not always possible using the latest mass produced commercial chips and circuit design methodologies.

Depending on the platform, the size envelope available to install a data acquisition chassis will vary. For space applications this will typically be highly limited. However there is a limitation to how small you can make a data acquisition chassis which houses a particular configuration of data acquisition cards

The amount of wiring required on a platform should be kept to a minimum as more wiring creates problems such as the time taken to define and install the wiring, the necessity to drill holes through structures, and the sheer weight of the cables. One way to reduce the quantity of wiring is to move the data acquisition chassis closer to the sensors. This has the advantage of replacing a section of the wiring loom with a single Ethernet cable from the chassis. As the data acquisition chassis moves closer and closer to the sensors the available locations where a chassis can be installed get smaller.

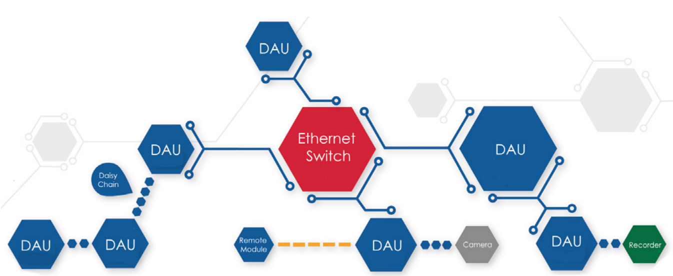


Figure 3: Typically COTS are easily scalable using network technologies

One solution for these locations could be the creation of a dedicated acquisition box which fits in the required dimensions with a small number of measurements. However, a dedicated acquisition box will solve the acquisition needs of only one location on one test article. A new box would need to be developed for every other location, which would typically have a different number and different types of measurements. The way to solve this generally would be to create a miniature modular chassis which could be populated with miniature acquisition cards.

Unfortunately, even this approach has its limitations. As noted previously the smallest modular chassis will typically require an acquisition card, an encoder/transmitter and a power supply. As the data acquisition chassis get smaller the power supply becomes a larger percentage of the volume. This is due to the fact that any piece of equipment which is connected to spacecraft power must comply with quality standards to ensure that it can be used safely on the spacecraft.

One approach to fitting the acquisition modules into even smaller spaces is to mount the acquisition module itself in a separate location to the chassis. This acquisition module would send its acquired data back to the chassis via a serial cable from which it would also be powered. This would ensure that the acquisition module could fit in a space that was just marginally larger than its own dimensions. It is then possible to connect a number of these remote modules to single chassis to allow a network of miniature acquisition modules to be placed in the smallest of spaces on the spacecraft.

Meeting Environmental Challenges

Reliability is key for aerospace applications and this is especially true for space. If the acquisition chassis malfunctions during flight then valuable data will be lost, or worse, the mission could fail. It has been shown that designing data acquisition equipment using FPGA based state machines produces extremely reliable systems. Even if the system gets into an unforeseen state due to power dips during flight it will cycle out of that state within one acquisition cycle and begin operating normally again. It is quite common for processor based systems to not recover fully after such an event. Also in the event of a brief loss of power to the acquisition chassis, a chassis designed using an FPGA based state machine approach will begin acquiring data immediately after resumption of power. This is due to the fact that there are no processors which need to reboot. Acquiring data immediately on power up enables test points to be completed even when there is a temporary power interruption to the acquisition system.

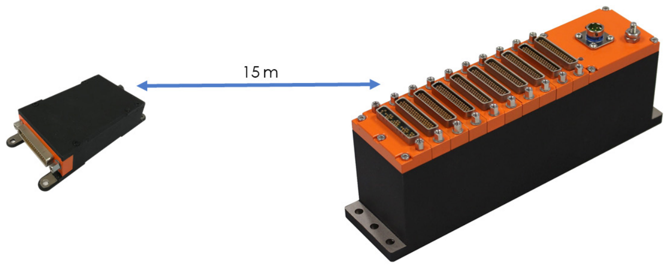


Figure 4: The ability to host modules outside of a main chassis means smaller locations can be accessed without having to create bespoke DAUs

Systems without a specialized radiation tolerant design are perfectly suitable for some space applications (e.g. launcher lower stage data handling, and short duration sub-orbital missions) and the savings are significant in comparison to radiation hardened ones, as the standard COTS flight test hardware is already highly ruggedized and designed for low size, weight and power (SWaP) requirements. This approach of using COTS electronics in space has been fully proven with the majority of new space missions now utilizing COTS for these kinds of applications.

Finding a Cost Appropriate Balance

Space COTS may not be suitable for applications which require some level of radiation tolerance. One of the reasons electronics, computers, and other equipment built for space are so expensive is that they are designed to withstand a certain level of radiation that COTS electronic equipment may not survive or become unreliable if subjected to.

Engineers can take one of two approaches to designing electronics that will be exposed to significant radiation doses: they either make it radiation-hardened, meaning the inherent technology provides protection from radiation, or radiation-tolerant, which means there is acceptance of some degree of performance loss from exposure to the radiation.

A designer could build a system from COTS commercial components that meet the functional requirements and other environmental requirements of the mission (vibration, shock, temperature etc.). The designer knows that there is some radiation tolerance inherent in the design – most commercial components are radiation tolerant to several krad – and hopes that the system will continue to function in a radiation environment. The trade-off here is that with this low cost approach, reliability may be compromised.

The designer could seek to mitigate the risk associated with their system selection by carrying out a series of ground radiation tests on the equipment to see how it performs when exposed to the expected mission radiation profile with some design margin. This may be an acceptable approach for low-dose radiation missions. However, is there a middle ground between these two where the reliability requirements of a system for a given mission are enhanced while at the same time meeting with the program budget and schedule requirements?

There is an approach based on a new type of chassis backplane, called the “smart backplane”. This straddles the cost effective approach of space COTS with the increased radiation tolerance required by some applications. In essence, it gives the chassis a way to detect any problems created by radiation and quickly reset a module or isolate it. It enables integrators to use existing, affordable COTS modules in a space radiation environment. This “Radiation Tolerant Space COTS” approach leads to faster time to deployment with significantly lowered costs, as well as the design, certification, and manufacture of space avionics.

A radiation hardened system will offer a lower risk, but it comes at a high cost. There are many mission profiles where lowering the level of space qualification is acceptable and the cost savings are significant enough to justify an increased risk of failure. This risk of failure must be kept below a certain level so there does need to be careful consideration given to each system, and the interaction between them. Using a COTS based smart backplane system, which mixes radiation tolerant and hardened components is a solution which provides high levels of reliability without being fully hardened. This will be typically be at least half the cost of a fully radiation hardened alternative.

Curtiss-Wright Solution

Curtiss-Wright addresses these many demands with flexible, rugged space data handling equipment that’s based on a cost-effective COTS approach. For the last 25 years, Curtiss-Wright has been supplying modular rugged data acquisition and recording systems to the flight test market. The basic building blocks of these systems is a fixed volume rugged chassis which can accept modular data acquisition cards to gather data from a variety of sensor types. Inherent in the design are features that actively mitigate against Single Event Upset (SEU) effects. The main feature is what is known as the acquisition cycle. The DAU operates as a collection of synchronized state machines that follow a schedule which occurs once per acquisition cycle. As part

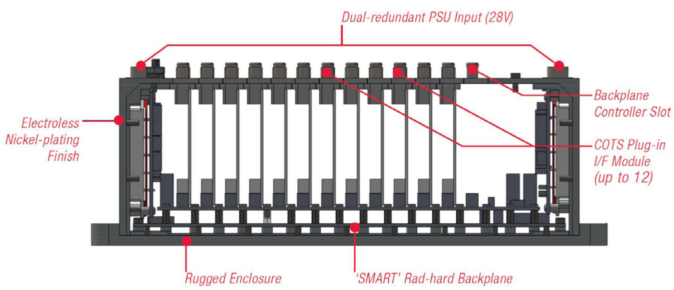


Figure 5: The Smart Backplane design balances cost against risk

of the acquisition cycle, the RAM is refreshed. Therefore any SEUs that occur in RAM are overwritten within one acquisition cycle time. An acquisition cycle time could be anywhere from 100 microseconds up to 2 seconds in length.

Curtiss-Wright space data handling systems have already been proven in a variety of space missions, and we expect to see some additional dramatic proof, in the form of several more applications currently in development stages. For example, Curtiss-Wright provides equipment based on the same core COTS space data handling systems that has been used successfully in a wide variety of space missions from test aircraft, to launchers, to re-entry vehicles to the international space station. Recently, engineers at The Boeing Company selected Curtiss-Wright Defense Solutions to supply rugged data-handling avionics for the Crew Space Transportation (CST)-100 spacecraft. The equipment gathers data from critical vehicle sensors used by on-board computers to make decisions during the flight of the CST-100, which is scheduled to undergo orbital test flights this year.

Thus far, Curtiss-Wright has been primarily providing its Acra KAM-500 product line into various space organizations globally – both as space COTS and using chassis with a Smart Backplane that takes a radiation-tolerant approach for missions where significant radiation is encountered. In order to meet the increasing demands of smaller size, lower weight, and increased data demands, Curtiss-Wright has developed the Axon.

The Axon is an ultra-compact data acquisition system that is ideal as a remote node or as a standalone chassis. It builds on Curtiss-Wright's heritage as a leading supplier of rugged reliable data acquisition and works seamlessly with the widely used Acra KAM-500 DAU chassis. Axon supports the same data formats as the KAM-500, and both can be configured using the same setup software. Additionally, data from both systems can be synchronized easily using a protocol such as the IEEE 1588 Precision Time Protocol (PTP).

The Axon uses hardware-based acquisition engines to minimize data loss, support deterministic operation, and ensure rapid recovery in the case of a power brownout. Axon uses a high-speed serial backplane (1 Gbps dedicated link per module) to ensure future high data rates are supported. This design also allows off-the-shelf data acquisition modules to be placed in ultra-miniature "Axonite" housings and located remotely which can be separated from the chassis by up to 15 meters. Locating data acquisition closer to the sensors can significantly decrease the installation time and cost of the instrumentation while simultaneously reducing wiring weight.

Further flexibility is provided by Axon's dual Gigabit Ethernet outputs, which simplify the addition of Ethernet nodes or allow multiple DAU chassis to be daisy chained together. An on-board processor speeds configuration, pre-flight checks, and in-service firmware upgrading. All these features make Axon an ideal choice for space applications. Axon has already been selected for a high profile space application on a small launcher due to its ability to handle large amounts of data in such a small footprint, on the order of 10x a comparable solutions. At the time of writing, Axon is new to the market, but design provisions were made during its inceptions to ensure that a radiation tolerant variant can be facilitated in the near term.

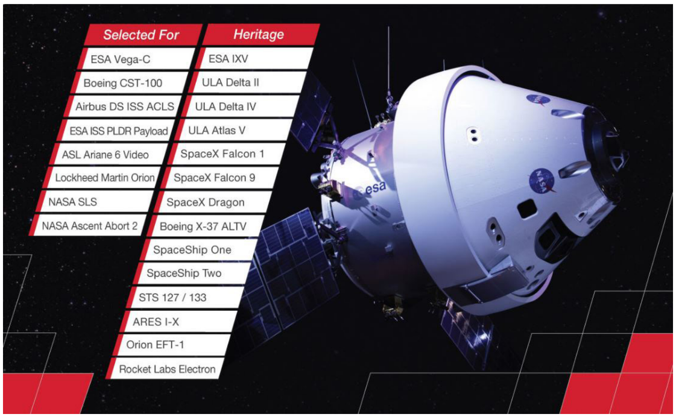
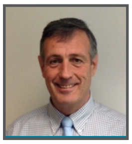


Figure 6: Curtiss Wright has a long heritage in providing space COTS and radiation tolerant solutions to the industry

Authors



Alan Murphy
US Director of Technology, Avionics & Electronics
Curtiss-Wright Defense Solutions

Danny Gleeson
Space Business Development Manager
Curtiss-Wright Defense Solutions

Jerry Festa
Sr. Manager, Program Management
Curtiss-Wright Defense Solutions

Stephen Willis BEng, MPhil, PGDip,
Marketing Portfolio Manager
Curtiss-Wright Defense Solutions

Conclusion

Space missions present extreme environments for electronic equipment including high levels of vibration, shock, temperature extremes, vacuum, and exposure to radiation. These can render some equipment useless or unreliable. Most rugged aerospace COTS equipment will struggle to cope with the effects of radiation but can do so using radiation hardened electronics with one big trade-off: cost. Increasing commercial pressures are putting focus on keeping costs to a minimum and radiation hardened electronics can form a significant chunk of the cost required for a space mission.

As the space launch market moves towards smaller launchers, everything onboard needs to be smaller, lighter, and lower cost. This presents a challenge to data acquisition system vendors such as Curtiss-Wright. Our extensive experience and knowledge leading the industry in space COTS and radiation tolerant solutions has been greatly enhanced with the launch of Axon. With its smaller size and weight, increased speed, and ability to remotely locate modules, we are confident that it will soon establish itself and indispensable to small launcher, and indeed all space, applications.

Learn More

White Papers

- Radiation Testing of COTS Data Acquisition Electronics for Space Applications
- Addressing the Environmental and Operational Issues for Data Acquisition Systems Onboard Space Launch Vehicles

Case Studies

- Small Launcher Development Flight Instrumentation Avionics Using Space COTS
- Rugged ‘Space COTS’ DAU for use on the International Space Station

Curtiss-Wright Products

- Space Data Handling