Ultra-Small Form Factor Mission Systems: Great Things Come in Small Packages

CURTISS-WRIGHT

DEFENSE SOLUTIONS

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- Ultra-small form factor systems
- Rugged system miniaturization
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Introduction

Aerospace and defense systems integrators continue to push for reductions in size, weight, power, and cost (SWaP-C) to support advanced sensor/vetronics payloads onboard manned and unmanned platforms. Fortunately, ground-breaking miniaturization of mission processor and network switch subsystems are enabling UAS (unmanned air system), UGV (unmanned ground vehicle), UUV (unmanned undersea vehicle), USV (unmanned surface vehicle), as well as manned fighter aircraft, helicopter, and tactical ground vehicle platforms to expand their mission capabilities.

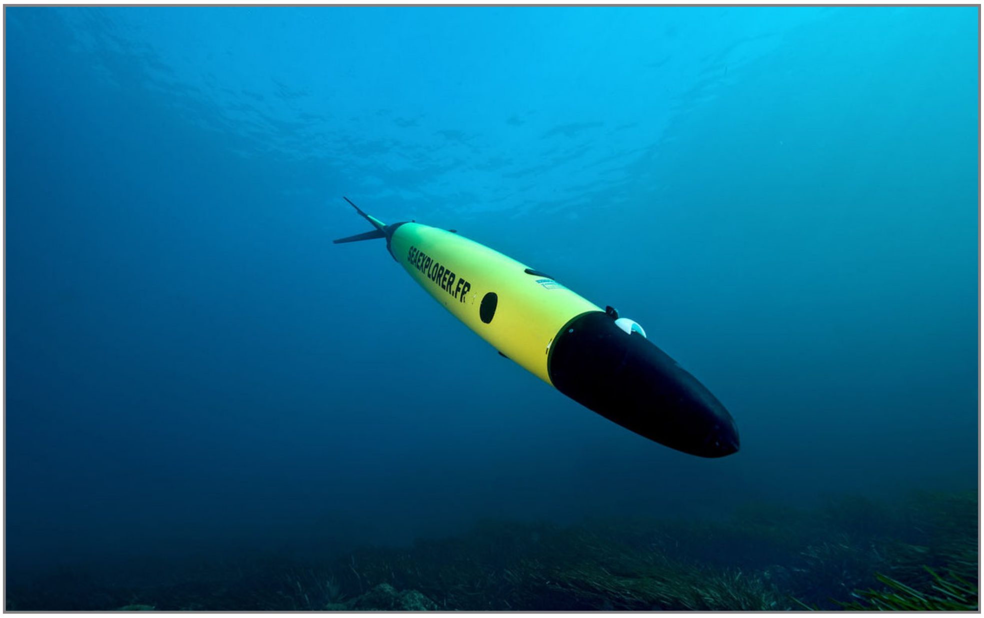

Figure 1: SWaP constrained UUV with integrated sensor payload
Photo Credit: Alcen Group

Fortuitously, COTS technology to shrink electronic subsystems is rolling out and enabling systems integrators to more effectively support technology insertion of advanced processor and network backbone architectures. Size and weight constrained platforms often require multiple computer processing elements and sensors as part of their vehicle electronics payloads that are ultimately interconnected to gather and share information. This need to fit more electronics into a limited space envelope is driving the necessity for smaller and smaller processor and network connectivity solutions.

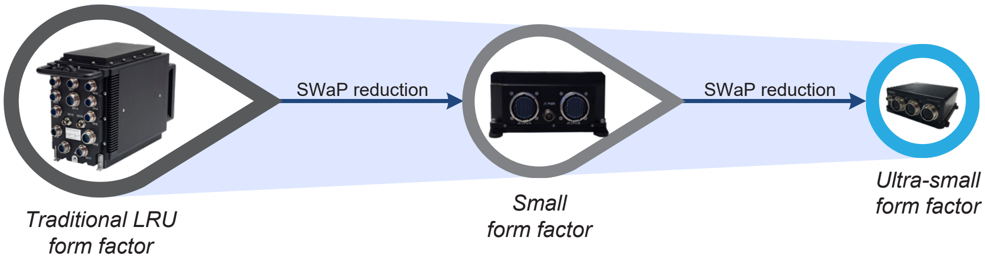

Figure 2: Evolutionary SWaP reduction of electronics payloads mission systems

The following white paper will introduce a new class of highly capable rugged COTS mission systems known as ultra-small form factor (USFF) and highlight how these line replaceable units (LRUs) are helping to drive down cost, capability tradeoffs, and SWaP in size and weight-sensitive platforms.

Optimal SWaP is Relative

What constitutes optimal SWaP for a particular electronics LRU varies greatly depending on the target platform and application. In the commercial UAS market, suppliers such as Facebook, Google, and Amazon are developing business models around UAS platforms that in some cases are only nominally larger in scale than hobbyist drones. The context for SWaP in the UAS space, whether commercial or military, is typically dictated by the size of the payload that a platform can carry. The platform's mission is often driven by the capabilities brought by the payload. For example, in contrast to the small commercial UASs, consider a military high-altitude long-endurance (HALE) platform that can carry 1000 pounds (~450 kg) of payload electronics. These platforms are often being used for persistent intelligence, surveillance, and reconnaissance (ISR) use cases.

In comparison, the small commercial UAS more typically will have payload capability of a few pounds or less. Designers of these systems may be satisfied to get an HD camera onboard their UAS that flies for only about 30 minutes due to the limitations of the aircraft's battery. For such small platforms, both airborne and ground, micro-miniaturization of systems becomes very desirable.

Cost of SWaP

Systems integrators often look at the operational and logistical impact of the electronics that are added to an aircraft or vehicle platform. Some UAS suppliers go as far as breaking down the cost of every pound (or kilogram) of payload weight in terms of cost-per-pound/kilo. After all, there are potential tradeoffs made as payload capacity is divided up between electronics, fuel, and ammunition, etc. For the most part, UGVs, UUVs, USVs, UAVs are smaller platforms, and generally speaking their mission and purpose is to serve as a sensor host for information gathering. These sensors can include FLIR cameras, radars, and other types of imaging technology to conduct surveillance, and capture video or photos or mapping information. Shrinking the physical size and weight of their payload electronics can translate into not only tangible cost savings, but also the ability to add more sensors and C4ISR equipment to enhance operational mission capabilities for the end user.

To further illustrate how much SWaP impacts platform cost, let's discuss three numbers: 1, 30 and 60. As a data point, one major North American UAS supplier has calculated that for every one (1) pound of weight they can eliminate from their UAS platform dedicated to ISR missions, they save approximately $30K in operational cost for the vehicle. For their combat UAS platform, they save even more, approximately $60K per pound. This look at financial implications as well as mission capability tradeoffs provides transparency into why system integrators are pushing to shrink the physical size and weight of integrated payload electronics and to optimize SWaP for on-board equipment.

Figure 3: Optimizing SWaP is key to UAS platforms that integrate advanced ISR electronics payloads.
Photo Credit: Northrop Grumman

USFF Ethernet Switch for UAS

In addition to cost impact, SWaP can affect feasibility for implementing mission capabilities. A major U.S. Army tactical UAS recently underwent a tech refresh to add an onboard network backbone, involving the integration of a fully managed Ethernet switch. Launched from a trailer-mounted pneumatic catapult and used for reconnaissance, surveillance, and targeting applications, this particular UAS had a rather small airframe and payload bay. The customer performed a volumetric analysis and determined that the size available for a network switch LRU was limited to roughly the size of a pack of playing cards and about half a pound in weight. Since the electronics payload area wasn't generous in size, if the switch could not meet this form factor requirement, the UAS may not have been able to add the desired network readiness capability. This would diminish situational awareness, since the switch was intended to link an onboard video encoder, mission processor, and warfighter communications devices via a common Ethernet network.

Figure 4: USFF DuraNET 20-11 8-port GbE switch supports SWaP-constrained network backbone upgrades

At the time of this customer program, Curtiss-Wright offered multiple rugged COTS small form factor (SFF) Ethernet switches that met this program's functional requirements but all exceeded the allowable weight and size. In fact, based on the form factor constraints together with the electrically noisy platform environment (which required enhanced EMI signal integrity and protections), the customer could not identify any COTS product on the market that met their needs and delivery schedule requirements. Fortunately, Curtiss-Wright's product development roadmap included a much smaller switch system, which was accelerated to accommodate this UAS program and the general market demand. As a result, a rugged USFF, COTS switching solution was realized, one that met the weight constraints and was just 10 cubic inches in size (small enough to fit in hand). Only 10% of the size of the previous generation SFF Gigabit Ethernet (GbE) switch, this miniature network device has now flown with deployment in theater and has been specified into many other platforms with similar constraints.

Figure 5: Firescout MQ-8C helicopter UAS
Photo Credit: Northrop Grumman

Since the introduction of this miniature Ethernet switch, the unit has been broadly deployed in not only UAS platforms, but also fighter aircraft ISR sensor pods, helicopter sonar dipping systems, autonomous submarine networks, tactical ground vehicles, unmanned rotarcraft, and dozens of other SWaP-constrained platforms. The switch's wide adoption is a testament to the need for USFF devices and the diverse applications that benefit from them.

Technology Enablers for SWaP Reduction

In large part, the miniaturization of such devices is made possible by advancements in commercial technology. Three notable enablers in this regard include System-on-Chip (SoC) technology, intelligent power management technologies, and mechanical component miniaturization.

The latest semiconductor devices for computing and networking are more energy efficient than ever before and are evolving to include more functionality in the same physical packaging. With fewer discrete components to integrate, printed circuit card assemblies (PCBAs) can be smaller. Traditional system architecture might have previously factored in multiple separate component devices, whereas today system designers have SoC alternatives that combine processing, memory, other controllers, interfaces, and physical transceivers all on a single chip. In the case of the Parvus DuraNET® 20-11 (see figure 6), its integrated switch SoC includes not only a non-blocking Ethernet switch fabric, but also a MIPS processor (for management), fully integrated copper PHYs (physical transceivers), a DDR memory controller, and IEEE-1588 precision timing protocol (PTP) controller for highly accurate time stamping. This SoC approach has been a tremendous tool in the miniaturization of military electronics, particularly for low to mid-power devices.

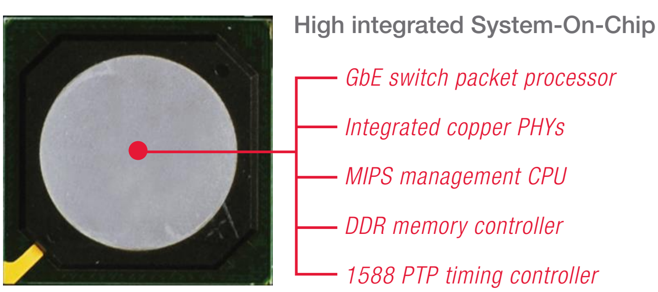

Figure 6: Ethernet switch SoC integrates packet processor, CPU, transceivers, more in single device

As Moore's Law continues to be exercised with next-gen integrated circuit (IC) design, the shrinking of semiconductor die sizes and addition of symmetric multi-core processing (SMP) are boosting performance while reducing power consumption. Intel-based / x86 processors have incorporated smart speed-stepping technologies to maximize performance yet throttle back to protect the device from thermal damage. Fueled by the explosive growth in Internet of Things (IOT) devices, Advanced RISC Machine (Arm) core processors similarly hone their own highly efficient power management capabilities in mobile devices. Further, Ethernet switch devices can now integrate advanced power management technologies in the switch core and physical transceivers, such as Energy Efficient Ethernet (IEEE-802.3az) and ActiPhy, which put unused ports in a low-power idle mode, keeping links active but consuming less power during lower data activity. These switches can also be intelligent enough to sense the length of the cable connection, limiting power for transmitting data, to say, 10 meters, rather than defaulting to the 100-meter Ethernet specification. In total, these technologies can result in cutting power consumption by 50% or more from traditional levels.

As manufacturers of SoC devices reduce the thermal needs of the silicon, they are also reducing the power dissipation requirements on the system, which means a smaller surface area required for cooling of the chassis. The mechanical size of the enclosure can also be smaller thanks to higher density connector technology. Traditional MIL-C-38999 connector shell sizes and MIL-STD-1472 Human Engineering recommendations for connector spacing have conventionally driven the size of the connector panel and enclosure. Newer generation micro-miniature MIL-performance connectors (see figure 7) can now provide the same or better physical, EMI, and electrical performance. These have higher density contacts and the physical size and weight of the connectors are roughly half that of traditional options. Consequently, there are now Ethernet switches and mission computers on the market today using these connectors that measure barely over one inch (~3 cm) tall.

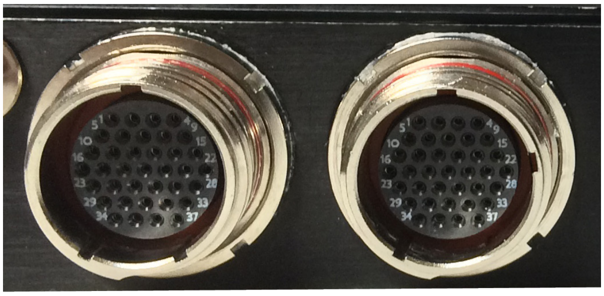

Figure 7: High-density micro-miniature connectors shrink enclosure size and drop weight

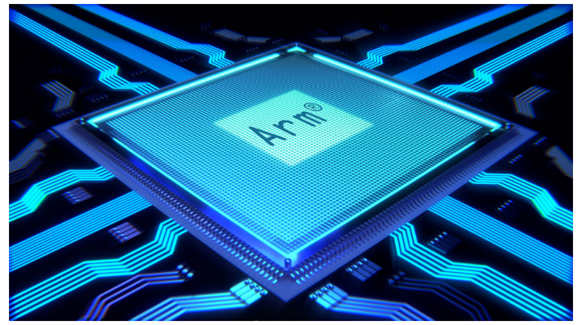

Figure 8: Arm CPU

Low-Power Arm and Intel

Innovative x86 and Arm-based processor technologies continue to integrate more capabilities into ever higher density semiconductor packages with optimized power management. These low-power CPUs are frequently used in system-on-chips (SoCs) that include not only multi-core microprocessors, but advanced peripherals, such as a graphics processing unit (GPU) without the need for separate discrete components, which helps reduce overall SWaP for embedded electronics. Intel's Atom processor is an example of an x86 SoC that integrates a lower-power quad-core CPU plus high definition Intel graphics and I/O chipset in a single package.

Because of the reduced instruction set nature of Arm architectures, Arm delivers superior million instructions per second (MIPS)-to-watt ratio with fewer transistors than processors based on complex instruction set computing (CISC) like x86 CPUs. Arm processors also reduce power consumption by operating at a lower clock frequency than x86 processors. In addition, Arm system-on-a-chip (SoC) vendors have integrated low-power states, such as power gating and clock gating, into their processors. Arm's lower power design lends itself nicely to SWaP-constrained applications by providing a reduced thermal solution in a low-weight processor.

USFF Mission Processors

Beyond switches, rugged COTS USFF mission processor systems are now available for extremely SWaP-constrained applications that deliver multi-core processing together with modularity and flexibility to meet specific vehicle sensor payload interface requirements.

Figure 9: USFF mission computers like the DuraCOR 313 provide small size with modular CPU and I/O architecture

Rugged, miniature modular mission computers (see figure 9) based on low-power Intel Atom (Elkhart Lake / Baytrail) or NVIDIA Jetson (TX2i Armv8) processors are available in form factors that weigh less than 2.0 pounds (0.9 kg) and measure a mere 2" tall (5.2 cm). These systems integrate a smaller-than-a-credit-card size Computer-on-Module (COM) with tightly integrated multi-core SoC technology together with a carrier board that offers multiple expansion slots for Mini-PCIe modules. In comparison with previous SFF systems based on Core i7 processors, these miniature processor boxes shave off 50%+ of the SWaP.

The latest x86 Intel-compatible solution from Curtiss-Wright is the DuraCOR 313 with a quad-core X6400E Series Atom processor, which boasts significant CPU, GPU, memory, security, and networking performance improvements over legacy E3845 Atom systems like the DuraCOR 311 and with only a marginal power consumption increase. The newer technology boosts RAM memory to 16GB DDR4, includes 11th gen Intel HD Graphics, integrated CAN 2.0 / CAN FD interfaces, a TPM security module, and support for low-latency Time Sensitive Networking (TSN) for deterministic Ethernet.

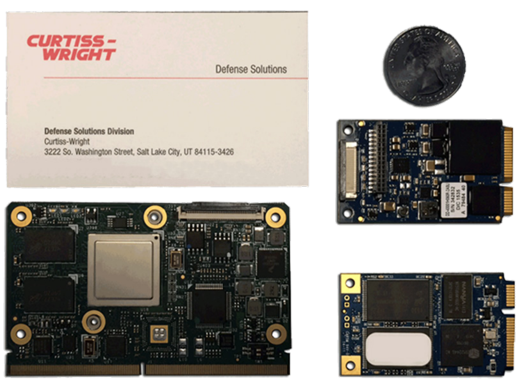

Figure 10: Smaller than a business card processor COM and Mini-PCIe modules

Unlike other SFF systems which might achieve small size at the cost of functionality, these USFF mission computers support a high level of I/O flexibility through a modular and open architecture I/O (see figure 11) that taps into the industrial ecosystem for Mini-PCIe I/O and mSATA SSD modules. Featuring multiple internal I/O expansion slots for application-specific add-on cards, these miniature modular processor systems not only provide the native I/O available from the Arm/Intel chipsets, but also optional add-on functionality over Mini PCI Express® cards, such as MIL-STD-1553, ARINC-429, CAN, or more DIO/serial/Ethernet ports—all without adding additional size to the box. Further, since this design approach is natively modular and standards-based, modified COTS (MCOTS) variants of these miniature mission systems can be quickly integrated through quick-turn, turn-key I/O integration services to reduce program risk, cost, and schedule with minimal NRE expense.

Based around a similar modular architecture as the 311/313, but with a 6-core 64-bit Armv8 processor and 256-core NVIDIA Pascal GPU is the Parvus DuraCOR 312 (see Figure 13). This USFF mission computer integrates an NVIDIA Jetson TX2i System on Module (SoM) with a massively parallel, many core architecture

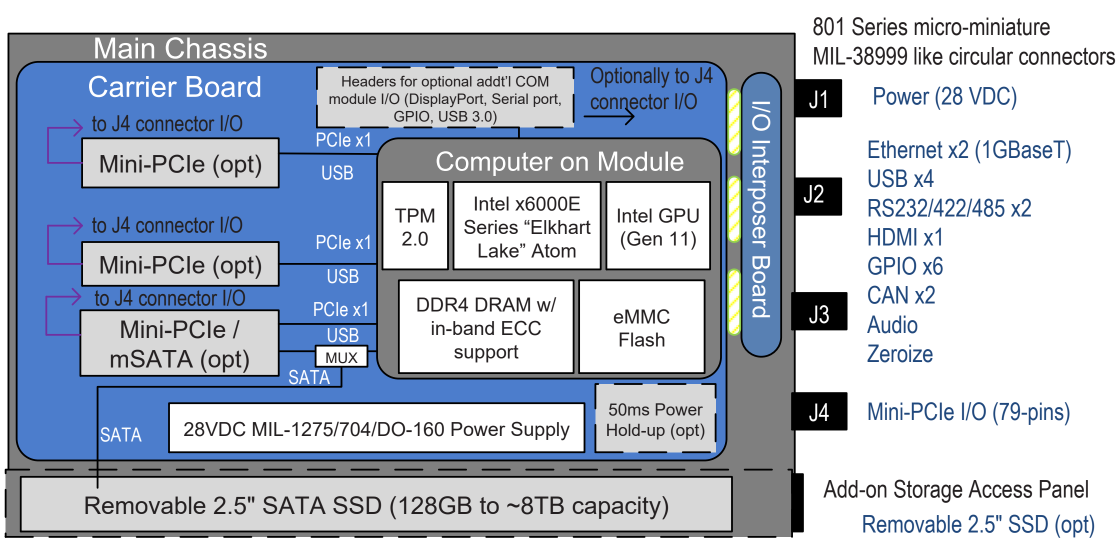

Figure 11: USFF DuraCOR 313's modular, open-standards-based CPU, I/O and storage architecture

boasting one of the highest computing FLOPS-per-watt architectures on the market. This powerful yet miniature system gives compute-intensive applications like intelligence surveillance and reconnaissance (ISR), electronic warfare, targeting systems, and deep learning the combination of a quad-core Cortex-A57 optimized for multi-threaded applications, a dual-core Denver 2 Arm processor optimized for single-threaded applications and an NVIDIA 256-core Pascal Graphics Processor Unit (GPU) for high-performance embedded computing (HPEC) needs.

Naturally, these small mission computers are designed to be as rugged as possible to perform optimally in the harsh environments endured by air, ground, and maritime platforms, whether the heat of desert tarmacs or the extreme cold of high altitudes. The use of the low-power processor architectures helps ensure these tiny mission computers can support a full range of military operating temperatures, from -40 to +71°C (-40 to +160ºF) without fans or active cooling requirements. To ensure their ability to perform under the extreme shock/vibration conditions, high altitude, and humidity required by mobile, tactical, aerospace, and ground vehicle applications, these rugged systems go through some of the most comprehensive pre-qualification testing for COTS products on the market, including extreme MIL-STD-810G, MIL-STD-461F, MIL-STD-1275D, MIL-STD-704F and RTCA/DO-160G test conditions for environmental, power and EMI (thermal, shock, vibration, dust, water, humidity, altitude, power spikes/surges, conducted/radiated emissions and susceptibility). Similar in approach to USFF switches, these computers are housed in rugged, sealed (IP67-rated dust and water proof) aluminum chassis with high-density, MIL-performance circular connectors.

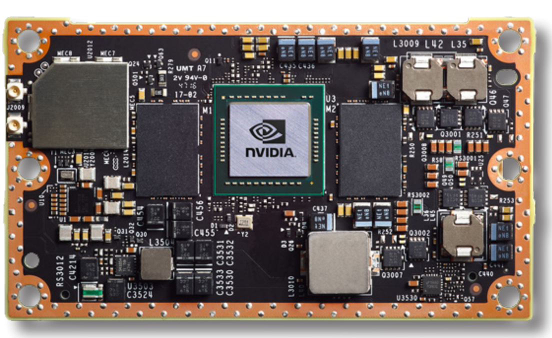

Figure 12: NVIDIA TX2i SOM module

Conclusion

The military and aerospace market maintains an insatiable appetite for smaller, lighter, and cheaper. Recent technological breakthroughs in SWaP-C reduction has yielded the introduction of USFF mission computer and networking systems. These systems' combination of small size, low-power multi-core processing, and flexible I/O represents the key design targets that system designers of unmanned and manned systems are seeking to add new Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) capabilities to their platforms. As technology continues to advance, electronic device density and packaging improvements will continue to enable smaller and more cost-effective unmanned/manned platforms. We've gone from traditional ATR size chassis to small form factor shoe box size embedded system LRUs to now USFF devices small enough to fit in the palm of your hand. Advancement in SWaP optimization should press forward at a rapid clip.

Figure 13: USFF mission computers like the DuraCOR 312 provide small size with modular CPU and I/O architecture

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