

Electronic Power and Thermal Management: A Critical Engineering Challenge for Next-Generation Unmanned Systems

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Unmanned vehicles have risen to a prominent role in military operations worldwide, and the trend for the next decade is toward even more complex systems, with increasing capabilities for guidance control, weaponry and surveillance. Highly complex systems require integrating a large number of electrical components within a very limited space. This creates challenges for power and thermal management not seen in previous generations of electronic systems. To be successful, plans must incorporate advanced power and thermal management strategies from the earliest stages of the design process and assess power and thermal issues across scales from the component to the system. This paper presents a comprehensive set of tools and methodologies that can contribute to addressing the challenges of thermal and power management encountered in these systems.

Greater Capabilities Deliver New Challenges

Unmanned systems are rapidly becoming an indispensable tool for military forces around the globe and are used across all domains — land, sea and air. This diverse and expanding use has resulted in the evolution of "unmanned X system" as a generic technology name, with the X most commonly referring to air (UAS), ground (UGS) or underwater (UUS).

Of these, the UAS is perhaps the most visible to the general public, due to its prominent role in recent conflicts, persistent surveillance of the Bin Laden compound, and views of Japan following the 2011 earthquake, tsunami and nuclear disaster.

As the value of UXS continues to be proven in the field, and as the current fiscal environment drives development of lower-cost and lower-risk plat-forms, it is inevitable that its use will continue to increase.

A few trends suggest how this technology will evolve and what it will offer in the future:

- **Flexibility**, including the ability of a platform to transition seamlessly from one mission requirement to the next, with plug-and-play modular payloads that support joint forces operation
- Platform capability improvement to include operation in adverse conditions, such as bad weather flight, more challenging terrain and rough seas, as well as increased endurance, reliability, speed and carrying capacity

UXS integrators and suppliers must concentrate on size, weight and power (SWAP). Supplying and managing system power requirements may be the critical limiting factor in achieving the long-term objectives that have been set for these programs. Electronic Power and Thermal Management: A Critical Engineering Challenge for Next-Generation Unmanned Systems

"While I want to transition the rather mature technologies to the fleet, we continue to wrestle with UUV energy and power." Admiral Gary Roughead

Former Chief of Naval Operations

- Payload capability expansion to support more advanced sensors and weapons systems, as well as electronic and counter-electronic warfare measures
- **Autonomy**, including greater embedded intelligence and decision making for autonomous, networked and swarming operation, and a shift from one human per UXS to one human per multiple UXS
- **Miniaturization**, as many research-level technologies explore the use of bio-inspired systems that are palm-sized or even smaller

Accompanying these technology developments is a potentially insatiable demand for power, which often conflicts with platform capability objectives. For example, ultra-endurance systems need to balance long-term sustained power against the additional weight of power generation and storage systems. Micro bio-inspired systems need to provide power for a practical operational duration within a shrinking platform footprint.

Fundamentally, for UXS integrators and suppliers, a key trade space centers on size, weight and power (SWAP). Supplying and managing system power requirements may be the critical limiting factor in achieving the long-term objectives that have been set for UXS.

Former Chief of Naval Operations Admiral Gary Roughead summed up this challenge at the Association of Unmanned Vehicles Conference in 2010, saying, "While I want to transition the rather mature [unmanned underwater vehicle (UUV)] technologies to the fleet, we continue to wrestle with UUV energy and power [1]."

The United States Department of Defense (DOD) has also stated that power sources are "critical enablers for all of the desired unmanned systems capabilities." Their most recent forecast goes on to declare that they believe "early scrutiny of the vehicle design will lead to improved power management [2]."

For companies seeking to capitalize on the growing need for unmanned systems, physics-based engineering simulation can play a valuable role in addressing the critical challenges of power and thermal management early in the design cycle.



"Early scrutiny of the vehicle design will lead to improved power management."

> United States Department of Defense Unmanned Systems Integrated Roadmap







Maximizing power while minimizing size and weight is critical to meeting future goals for UXS development.

The Role of Physics-Based Engineering Simulation

Physics-based simulation tools harness the power of computers to solve the fundamental equations of physics. Designers and analysts can use the software to create virtual representations of complete UXSs and their payloads for trade space analysis and optimization, all prior to physical testing.

The technology has been verified and validated in a range of industry sectors, particularly aerospace and defense communities. In some cases, the use of physics-based simulation is mandated by regulatory bodies.

Leading physics-based simulation software companies have been in operation for over 40 years, during which the benefits of leveraging the technology have been proven time and again — even helping some engineering firms rise above others in their fields. Assessing the most highly differentiated strategies between the best-in-class firms and laggards, independent research provider Aberdeen Group found that the systematic use of physics-based engineering simulation tools early in the engineering process was a standout factor [3].

These best-in-class companies:

- Meet quality targets 91 percent of the time, compared with a 79 percent industry average
- Meet cost targets 86 percent of the time, compared with a 76 percent industry average
- Launch on time 86 percent of the time, compared with a 69 percent industry average

In essence, consistently leveraging engineering simulation throughout the design process helps drive double-digit improvements in quality, cost and time performance when compared with companies that fail to embrace the technology.

What's more, research performed by the DOD revealed the staggering impact that physics-based engineering simulation can have. A three-year study reported that "for every dollar invested [in the software and computing infrastructure to support simulation], the return on investment is between \$6.78 and \$12.92." These are recorded returns of between 678 percent and 1,292 percent.

In terms of improving UXS power management, employing a physics-based simulation strategy is highly aligned with the DOD's call for early scrutiny of vehicle design [4].



Understanding and managing power issues is key to the SWAP trade space, as a more power-efficient design will allow a longer mission time or enable miniaturization of the unit to extend its application profile. These issues must be considered at every level – from the chip to the system as a whole.

Architecture	Intellectual Property	System-on-Chip	Package System (PCB)
PowerArtist	Totem Power Budgeting	RedHawk	Sentinel
ſ	TI. & Gate Power Reduction Power Delivery Integrity IP Integration, Soc PDN Integrity & Reliability Sign-off Power-Induced Noise Immunity Chip-Package-System Electrical & Thermal Convergence		

Power analysis and optimization solutions from Apache enable power reduction and ensure integrity of the power delivery network.



Raven micro air vehicle Image courtesy U.S. Air Force.

Applying Physics-Based Simulation to SWAP Trade Space

In the design of UXS electronics, size, weight and power are three major challenges that determine the unmanned system's application profile, endurance and performance. Of these, power is the central issue, since it determines the size, and hence the weight, of the required energy storage or generation solution, as well as the endurance of the entire system under operating conditions. Clearly, understanding and managing power issues is key to the SWAP trade space, as a more power-efficient design will allow a longer mission time or enable miniaturization of the unit to extend its application profile.

At the core of electronic systems are integrated circuits (ICs) and associated software that control system behavior. Reliability of the IC operation is critical to the success of a mission, and power management of the IC in terms of consumption, integrity and its impact on system reliability are key concerns that need to be addressed. These issues must be considered at every level — from the chip to the system as a whole. The process should begin very early in the design cycle, when architectural decisions are made, and should be applied consistently throughout the implementation process to the final delivery of the system.

A suite of power and thermal management simulation solutions from Apache Design, a subsidiary of ANSYS, provides the tools necessary to meet the power consumption, integrity and system reliability requirements of UXS electronics.

Power Management and Reduction

Power management must be addressed early in the design phase, at the architectural level, to ensure a long-enduring unit. Two of the smallest unmanned air systems currently in operation rely solely on batteries to power their motors and on-board electronic systems. Both the WASP III and Raven micro air vehicles (MAVS) can fly for approximately 45 minutes to 1 hour before they need to land and recharge their batteries [5]. Reducing power consumption in these designs, therefore, is critical to the ability to deliver real-time surveillance information.

These MAVs are by no means simple systems, as they carry the same amount of on-board cameras and surveillance capabilities as larger, highend UASs. Unnecessary power consumption of UAS chips will lead not only to early depletion of their battery power sources, but to electrical and thermal reliability issues, which can shorten the UAS's expected lifetime and render it unreliable in the field.





Analysis-driven reduction quickly enables intelligent decisions for maximum power savings with minimum design impact. *Image courtesy Apache Design, Inc.*

"L-3 IEC is very happy with Apache's PowerArtist tool. The power estimate provided by the tool came very close to what was measured in the lab. All in all, the tool worked as advertised. What more can you ask for?" Brad Bryant ASIC Design Manager

L3 Communications Interstate Electronics Corp.



RedHawk dynamic voltage drop map to validate chip-level power integrity under a given mission scenario *Image courtesy Apache Design, Inc.*

The first step in power management is optimization of power consumption in the system. This needs to start at the beginning of the design stage, when the functional specification of the system is translated into registertransfer-language (RTL) code describing the implementation of the electronic system on a behavioral level. There may be many possible implementations that will result in the same system function, all varying widely in power consumption. A good designer will draw upon experience to optimize the RTL code to implement the necessary functionality in a power-efficient way. But given the size and complexity of electronics in modern military systems, analyzing RTL code organically is becoming impractical. Instead, this requires the support of dedicated optimization tools capable of analyzing the full complexity of the system implementation.

The PowerArtist[™] software tool analyzes the RTL code that describes the implementation of the electronic system and identifies improvements that will reduce power consumption without changing system functionality. This optimization results in an implementation of the required system functionality with the least possible power consumption, which is a cornerstone of superior power management in complex electronic systems.

Reducing a component's power consumption also reduces the amount of heat it generates, which helps ensure that the system will operate more reliably in its target operation environment. Optimized power management, therefore, is an integral part of thermal management of a system.

Power Integrity

The next step in power management is ensuring the integrity of the power delivery in the electronic system. In systems that are optimized for power consumption, functional blocks not needed at a given time are deactivated, thereby avoiding wasted power and unnecessary heat generation. As the mission progresses, new functional blocks are continually activated while others are deactivated, causing surges on the power supply. Similar to the way a light bulb flickers when other electrical products are switching on, the noise generated by these power surges interferes with power delivery to the active components in the system. A power integrity analysis can help ensure that the power supply meets the requirements specified for each component necessary for flawless operation.

The RedHawk[™] software tool from Apache analyzes power integrity for all components and identifies design changes necessary to guarantee accurate system operation under all mission scenarios. RedHawk power integrity analysis takes into consideration the system environment by including an electrical model of the package and board, generated by ANSYS® extraction software. Analysis results from RedHawk enable optimization of the IC packaging solution, especially when migrating to smaller packages or examining design and cost trade-offs between packaging solutions.



Thermal Induced Stress



Advanced thermal modeling simulates heat transport, distribution and dissipation to analyze heat stress. *Image courtesy Apache Design, Inc.*



The package and board solution of military electronic systems face the challenge of electromagnetic interference from components.

Image courtesy ANSYS.

Thermal Management

In addition, thermal management of the electronic system is required to ensure the functionality of an electronic system. Thermal management has become increasingly challenging with the trend toward UAS miniaturization, as demonstrated by MAV units, and the demand for integrating greater control and surveillance capabilities into an advanced electronic system, which drive up system power. As electronic components consume power, they also generate heat that has to be removed from components to avoid overheating and loss of reliable operation. While electronic components continuously scale in size due to process improvements following Moore's Law, cooling solutions are not scaling at the same rate and are becoming a major bottleneck for further miniaturization.

As a consequence, thermal management cannot be treated as an afterthought anymore; it has to be an integral part of system design. Thermal management requires optimization of heat generation and heat dissipation, making it a multiphysics problem. Heat generation, linked to the power dissipation in the system, can be accurately predicted using RedHawk software. Heat transport and dissipation can be analyzed using ANSYS Icepak® advanced thermal modeling software, which simulates the heat transport in the IC package and cooling mechanisms and analyzes heat distribution in the system. This electrical and thermal analysis drives the proper selection of package options and cooling solutions.

Electromagnetic Interference and Electromagnetic Compatibility

Advanced military electronic systems, combining numerous electronic components in very limited space, are inherently prone to electromagnetic interference (EMI) concerns. Any operating electronic component radiates electromagnetic energy that can be received by other components and disturb their operation. In the case of advanced military electronics, the high density of components and their integration with sensitive sensory systems make EMI very challenging. For this reason, the U. S. military has developed, over many years, standards for electromagnetic compatibility (EMC) that must be met by each electronic system.

Controlling EMI and achieving compliance with EMC specifications has to be approached from two directions: controlling the emission of electromagnetic energy by each component and controlling the sensitivity to emission by other components. Two major sources of electromagnetic radiation are the transient switching of currents as well as power delivery network resonance, which can be effectively suppressed through careful design of the chip, package and PCB board supply system. This has been successfully used in automotive applications.





Current density limits decrease exponentially with increasing temperature, eroding reliability of devices in high-temperature environments due to electromigration. *Image courtesy Apache Design, Inc.*

RedHawk software analyses the activity of a component and simulates the electromagnetic excitation caused by this activity. Then Sentinel[™] software (from Apache) uses this excitation information and simulates the impact of its electromagnetic interference on the existing package and system environment. Based on these simulation results, the design is optimized to meet requirements for near-field and far-field electromagnetic field distribution. In this way, the radiation of each component is optimized to meet EMC compliance requirements.

Reliability

Military systems have to meet very high reliability standards, especially in mission-critical applications in which safety and security are dependent on the electronic system's reliable performance. This begins with reliable components. The growing use of commercial off-the-shelf (COTS) components in unmanned systems presents a new challenge for guaranteeing system reliability. While these COTS components have the advantage of reducing design cost and time to market for processors and field-programmable gate arrays (FPGA), the power consumed and heat generated bring up reliability concerns. This is especially true in military applications within extreme temperature environments, such as those encountered by Predator and Reaper drones deployed in Iraq and Afghanistan. As the DOD drives the need for COTS-based systems, there is an urgent need for reliability analysis. ANSYS and Apache have developed tools to address the major concerns associated with these electronic components, particularly lifetime limitation due to electromigration and electrostatic discharge (ESD).

Electromigration, the transport of metal particles due to current flow, is a major effect limiting the lifetime of electronic components. Electromigration impacts the integrity of chip interconnects, leading first to intermittent disruption of device functionality and ultimately to complete operational failure of the component, rendering it unreliable in the field. The rate of electromigration increases dramatically with temperature, creating a greater concern for systems operating in high-temperature environments.

RedHawk software can be used to analyze the compliance of chip interconnects with electromigration requirements for every wire, ensuring the complete component will fulfill its required lifetime, even in the extreme environmental conditions of military missions.

In addition, external events such as a human body touching an electronic device can lead to an electrostatic discharge (ESD), which could render the device inoperable if sufficient protection is not built into the design. For this reason, standards are in place for components used in military applications, to ensure the reliability of the device in the case of such an event [7]. Pathfinder™ software from Apache allows a comprehensive analysis of a device's ESD sensitivity and verifies compliance with ESD standards.



About Robert Harwood, Ph.D., and ANSYS, Inc.

Dr. Harwood is the aerospace and defense industry marketing director at ANSYS. Founded in 1970, ANSYS develops and globally markets engineering simulation software and technologies widely used by engineers, designers, researchers and students across a broad spectrum of industries and academia. The company focuses on the development of open and flexible solutions that enable users to analyze designs directly on the desktop, providing a common platform for fast, efficient on the development of open and flexible solutions that enable users to analyze designs directly on the desktop, providing a common platform for fast, efficient and cost-effective product development, from design concept to final-stage testing, validation and production.

About Margaret Schmitt and Apache Design, Inc.

Ms. Schmitt is an applications engineering director at Apache Design, specializing in the area of low-power and power/thermal management. She holds a masters degree in electrical engineering. Apache Design is a wholly owned subsidiary of ANSYS, Inc., enabling simulation-driven IC and electronic systems design by providing advanced chiplevel power analysis, optimization and sign-off solutions. Apache's products help the world's top semiconductor companies that serve a broad range of end-market applications gain competitive advantage by lowering power consumption, increasing operating performance, mitigating design risks, reducing system cost and shortening time to market. Visit www.apache-da.com for more information.

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Success for the Next Generation of UXS

Next-generation unmanned systems are being developed to meet growing requirements of field reconnaissance, strike capability and longer mission duration, as well as new fields of operation in land, sea and air. As the military seeks to expand the role of unmanned systems, industry must rise to the urgent challenge of ensuring that power supply requirements of these systems are met within their allotted power and thermal envelope. Only a multiphysics approach, initiated early in the design phase, can simulate the power consumption and thermal dissipation of these complex systems, enabling successful power reduction and thermal cooling solutions for onboard electronics. The power integrity of these systems and their ability to conform to reliability and emissions standards can be validated through ANSYS and Apache simulation solutions for the individual components as well as for comprehensive onboard electronic systems.

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ANSYS, Inc. is one of the world's leading engineering simulation software providers. Its technology has enabled customers to predict with accuracy that their product designs will thrive in the real world. The companyoffers a common platform of fully integrated multiphysics software tools designed to optimize product development processes for a wide range of industries, including aerospace, automotive, civil engineering, consumer products, chemical process, electronics, environmental, healthcare, marine, power, sports and others. Applied to design concept, final-stage testing, validation and trouble-shooting existing designs, software from ANSYS can significantly speed design and development times, reduce costs, and provide insight and understanding into product and process performance. Visit **www.ansys.com** for more information.