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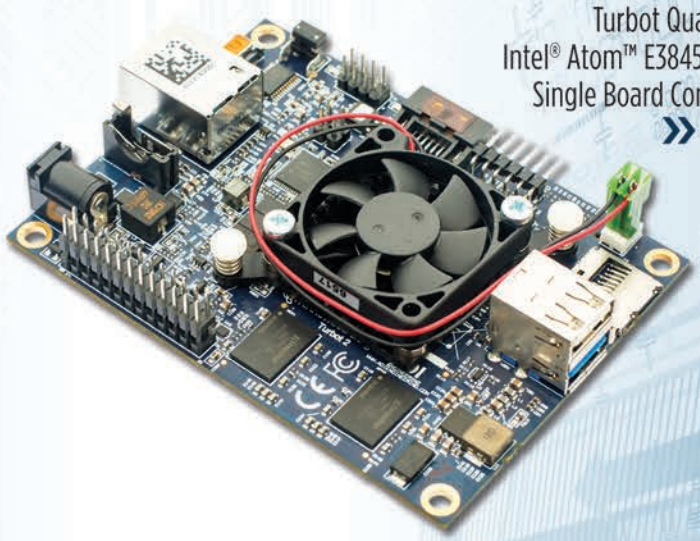

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PC/104 and small form factors

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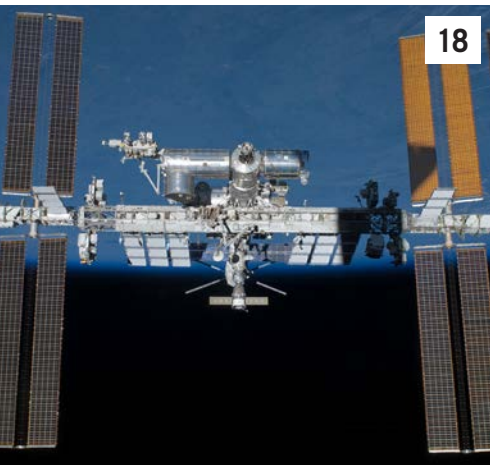
ON THE COVER:
The Winter 2016 *PC/104 and Small Form Factors* Buyer's Guide features applicable products used in the communications and networking, development, industrial automation and control, IoT, and military and aerospace industries. Featured on the cover: Turbot Quad Core SBC from Minnowboard.org.



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PC/104 Consortium

By Stephen St. Amant, PC/104 Consortium President

A go-to embedded solution

There was a time when I watched the cooking competition television show "Chopped" somewhat regularly. It's an intense ingredients-based culinary challenge that pushes chefs to their limits under strict time constraints. Amidst the nearly endless food combinations available to the contestants, it seems as though every episode I watched included one person (and sometimes two or three) who used mascarpone cheese. Often in the dessert round, the chef's storytelling voiceover (dripping with tension) would recount, "I ran to the pantry. I grabbed the mascarpone … "

To these chefs who were under pressure to excel on the highest levels, mascarpone was often a go-to. The cheese was versatile, tasted delicious, and had the potential to provide the basis for a winning dish.

Segue to embedded system design, if possible. Like some chefs have go-to ingredients, some engineers and system integrators have go-to form factors. For many, that versatile go-to is PC/104. It's a rock-solid architecture supported by a thriving ecosystem of compatible, stackable modules. It's been a proven winner in embedded applications for nearly 25 years, and it continues to evolve to support the latest technologies. Let's look at why PC/104 is so often favored:

- **Great selection.** PC/104 runs the gamut. Drawing from many seasoned manufacturers, embedded system designers have excellent choices when it comes to PC/104. There are hundreds of commercial off-the-shelf (COTS) "104" modules in the marketplace with stackable PCI Express, PCI, and ISA buses. The Consortium specifications include the latest PCIe/104 and PCI/104-Express, as well as PC/104, PC/104-Plus, PCI-104, EPIC, EPIC Express, EBX, and EBX Express specs.

  Mechanically, complete PC/104 systems can be as minimalist as a single module, or they can be more complex and include a dozen add-in cards. Likewise, in functionality, a PC/104 solution can be simple in the task it addresses (data transfer or storage, for instance) or very sophisticated (such as high-end digital signal processing and Serial RapidIO interconnects). The PC/104 ecosystem is a wide-ranging and valuable resource for engineers across many different vertical markets.

- **Tailored expertise.** Some of the Consortium's member companies have been building to the various PC/104 specifications for over three decades. That's an impressively deep bench, loaded with industry expertise. This longevity of use enables designers and project managers to curate their solutions from multiple manufacturers who offer focused expertise in diverse signal technologies and packaging capabilities. In addition, the technical support offered by these companies is among the finest in the embedded marketplace. Compatibility is a hallmark of the PC/104 architecture, and PC/104 companies know that making products that work together is a must. As a result, system integrators are able to configure solutions that often enjoy seamless cross-vendor interoperability.
- **Rapid uptime.** Because of the many COTS PC/104 products available, system designers are able to configure systems rapidly, especially compared to engineering teams building solutions from scratch. With stackable 104 modules, complex proof-of-concept configurations and even fully deployable systems can be built within days or weeks, rather than in months or years. Streamlined and straightforward system design can mean serious cost-savings and better overall project management.
- **Combating obsolescence.** PC/104 is a modular architecture. With this modularity comes the ability to field systems that can be repaired, upgraded, and even retrofitted when necessary. This means that overall life cycles can be extended and investments can be protected. The industry knows very well that some components ultimately go EOL [end-of-life]; this is expected. Where PC/104 shines lies in its ability to anticipate EOL situations and afford end users the possibility of addressing them without needing to pursue cost-prohibitive complete redesigns.
- **Earning new admirers.** The embedded marketspace is continuously growing, and so are many vertical markets. As engineers face new challenges, they seek to design new solutions. Enter PC/104: The rugged, modular architecture continues to be an attractive choice for embedded engineers addressing cutting-edge application needs in aerospace, defense, security, transportation, mining, medicine, gaming, energy, and any number of other areas including the omnipresent Internet of Things (IoT).

So, next time you're ready to design a system, make sure you have PC/104 on the menu. For many of us it's a go-to, and it delivers exceptionally good results. Keep up with the latest PC/104 products, news and specification updates at www.pc104.org.

small MATTERS

By Rory Dear, European Editor/Technical Contributor

PC/104 architecture maintains relevance in a competitive field

PC/104 is into its third decade, standing the test of time, while myriad form factors of yesteryear have faded into irrelevance. So why is PC/104 so persistent? How has it survived? The simple answer for me is the tireless work of the consortium that lies behind its continued success. A collaboration of companies with a common vision, it was formed in 1992 with 12 members but now has almost triple that. The PC/104 Consortium ensures PC/104's continued relevance. The spine of a PC/104 stack is the desktop-derived peripheral bus, arguably the key evolution since 1992 (Figure 1).

The PC/104 Consortium's continued role is to revise and evolve the form factor to encompass the next generation of peripheral bus, from a (now relatively) low 4.77 MHz ISA bus to the 8 GHz that's available today. The consortium recognizes the importance of backwards compatibility and longevity. Therefore, new revisions of the spec optionally retain the previous generation of peripheral bus to satisfy innumerable legacy PC/104 applications.

The form factor's unique selling point is of course its stackability, a trait that it has exclusively retained while the remaining vast infrastructure of embedded and desktop computing solutions continue to rely on a traditional backplane format. The benefit of stacking is functional scalability: the ability to expand or contract functionality, to facilitate in-situ upgrades of legacy installations, or offer a range of configurations effortlessly from a single base product.

The evolution of PC/104 is analogous to that of the ubiquitous Ford Mustang. The old adage "if it ain't broke, don't fix it" applies to both in the retention of their original unadulterated purity, and it's under the hood where technology has kept both at the forefront of their respective industries – PC/104's new engine is PCI Express (known as PCIe).

PCIe integration into PC/104

The PCIe/104 and PCI/104-Express specifications were formally adopted by PC/104 Consortium voting members in 2008, with the former exclusively providing the PCIe peripheral bus and the latter also retaining the previous-generation PCI bus for its famed legacy support. Revisions to larger-footprint standard form factors meant that EPIC-Express and EBX-Express, while not supporting a stackthrough architecture,

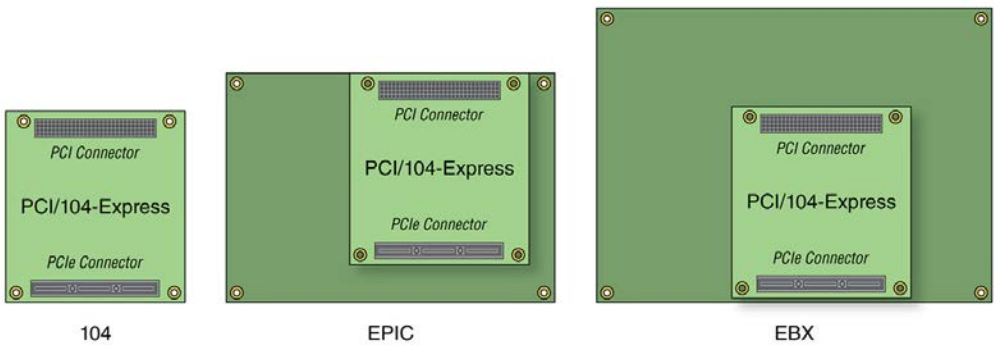
Figure 1 | WinSystems' PCM-VDX-2-512-ST is a fanless PC/104 board with the desktop-derived peripheral bus.

represent valid baseboards to suitably support a rising PCIe/104 peripheral stack (Figure 2).

PCIe/104 satisfies the breadth of I/O diversity required without falling into the incompatibility trap that system-on-module (SoM) form factors invariably experience due to multiplexed pin assignments. PCIe/104 offers two distinct types of fixed I/O configurations that offer flexibility without sacrificing PC/104's scalable compatibility (Table 1). Type 1 offers a high-speed 1x16 or 2x8 PCIe link, providing 8 Gbps peripheral bus bandwidth for the intensive (invariably video) processing applications.

Where such bandwidth isn't needed, Type 2 trades this for dual USB 3.0, SATA,

Figure 2
EPIC-Express and EBX-Express revised to support a rising PCIe/104 peripheral stack.



FEATURE	TYPE 1	TYPE 2
USB 2.0	2	2
SMB	1	1
PCIe x1	4	4
PCIe x4		2
PCIe x16	1	
USB 3.0		2
SATA		2
LPC		1
RTC Battery		1

Table 1 | Two fixed-I/O configurations offer flexibility without sacrificing scalable compatibility.

x4 PCIe links, and a low-pin-count (LPC) bus. Such a diverse range of possible stack configurations is underpinned by the bus's mechanical flexibility and built-in electronic dynamic compatibility. The flexibility and expandability of the bus and its mechanical layout allow different stack configurations to support an array of diverse project requirements. Intelligent Link Shifting automatically assigns PCIe links throughout the stack while a PCIe/104-to-PCI bridge peripheral board adds legacy PCI support where the choice of CPU module cannot.

The PCIe advantage

Due to the computing industry's obsession with backplane motherboard and slot daughterboard methodology, PC/104 finds itself as the only nonbackplane system supporting a PCIe peripheral bus. This reality translates to PC/104 being the only format that lets designers evolve existing solutions to include functionality not envisioned, or technology that didn't even exist, during the initial design phase.

The evolution of USB to version USB 3.0 has provided unprecedented bandwidth to hot-swappable peripheral devices evolving in parallel with the fixed PCIe bus to which it is effectively a subset. The ubiquitous adoption of both has driven costs so low today and their respective capabilities and pricing structure are so similar that they invariably go hand-in-hand, complementing each other to satisfy either fixed or removable peripheral devices. Such is the design of PCIe that a single high-speed x16 bus can be split to provide double the lanes at half the bandwidth, and so on.

The first beneficiaries of a new, higher-bandwidth peripheral bus are invariably graphics cards, always the first to push the bus-bandwidth boundaries and arguably the key driver in the commercial-computing arena when next-generation products get developed. In the embedded space – with ever-increasing die density and exponential improvements in integrated graphics chip sets – increasingly the traditional peripheral boards find themselves locally satisfied within a system-on-chip (SoC). This coverage negates the need for such peripheral bus bandwidth. Additionally, embedded-computing technology naturally strives for miniaturization.

The real-estate pressure of often redundant, large peripheral bus connectors in a design that doesn't fully utilize them poses a miniaturization bottleneck. One solution to this problem is OneBank. The PCIe/104 and PCI/104-Express specification defines three identical and adjacent connectors, integrated into one three-way connector. OneBank replaces that bank of three (superfluous in the majority of small-form-factor applications) with one connector that is identical to the first bank of both Type 1 and Type 2 PCIe/104 connectors. Maintaining the location of the first bank ensures compatibility with existing PCIe/104 boards as well as one another. Offering a 60 percent reduction in connector size, OneBank increases available printed circuit board (PCB) real estate and drives down cost. Support is also retained for lane shifting, the jumperless autoconfiguration of peripheral boards.

What's next for PC/104?

With the bandwidth boundaries of PCIe continuing to be pushed as hard as when it first landed, it's unlikely any entirely new peripheral bus will replace PCIe any time soon. The third generation of PCIe, currently implemented in PC/104, offers a bandwidth of 8 Gbps, which is overkill for everything but the latest high-performance applications. The fourth generation will double this to 16 Gbps, though the development of interconnects is even further ahead, ready to support 28 Gbps.

Managing COTS obsolescence for military systems

By Sally Cole

The short life cycles of commercial components create many obsolescence headaches for military electronic-system designers as they try to integrate these high-performance devices into air, ground, sea platforms that must last for decades, that have long system development cycles, and time-consuming testing procedures. As the military looks to leverage more open architectures and commercial off-the-shelf (COTS) technology, the challenge of managing the obsolescence that comes with COTS will only become more difficult.

Obsolescence is often hailed as "the dark side of COTS procurement" for the U.S. Department of Defense (DoD). Military platforms – many of which are expected to survive for at least 50 years – are becoming dependent upon commercial technology as a way to decrease costs.

But there are serious downsides to tapping COTS components that can become obsolete within 18 months – particularly when it comes to managing obsolescence issues. It poses numerous challenges for integrators, embedded suppliers, distributors, and aftermarket suppliers alike.

Can long life cycle military platforms coexist with COTS?

How are long life cycle military platforms able to coexist with COTS components that can become obsolete within 18 months?

This reality is a significant challenge, according to Christopher Bruns, director of component application engineering for Rockwell Collins in Cedar Rapids, Iowa. To deal with it, the company is "aligning itself with preferred suppliers that provide extended product life cycles," he says. "And we augment this with product road maps that include block update strategies to allow us to minimize the impact of obsolescence by making shorter duration buys when components go 'end of life.'"

Flexibility is another key piece of coexistence: "Customers want the flexibility to choose what's right for their program," says Richard Kirk, product manager for Abaco Systems in Huntsville, Alabama. "The first approach is committing to making a product available for a minimum of seven years. Then we can offer long-term support services, which means that the product is available as long as the customer needs it."

An alternative is to "design a series of 'technology-insertion' steps so customers can slot in new products with minimum integration effort," Kirk adds. "It will have the same pinout and specific new hardware features can be masked by the software."

Customers who bought a single-board computer (SBC) from Abaco in 1998 can obtain "essentially the same board nearly 20 years later, but with significantly more performance," Kirk points out. "This type of technology insertion strategy is popular with many customers because it's common for military platform capabilities to be upgraded during their lifetime. This is something that Abaco's customers factor in at a platform's outset, and our strategy is to allow them to do that with minimum cost and disruption – in effect a straight swap."

Not everyone believes COTS belong within military platforms, however. "The biggest problem is that the military is using commercial products, which aren't designed for longevity," says Dale Lillard, president of Lansdale Semiconductor in Tempe, Arizona. "Roughly one percent of semiconductor revenue comes from the military, so they're not exactly driving semiconductor manufacturers to keep producing their products. And life cycles are much shorter now, so the aftermarket is having a difficult time maintaining newer technologies."

Another issue is that "during the past 18 months, we've seen significant delays within our airspace in the Americas due to glitches and shutdowns of airline systems," says Rich Fitzgerald, vice president of business operations for Avnet in Phoenix, Arizona. "The suggestion that perhaps these glitches are not simple outages but the result of using COTS solutions in complex secured networks is concerning … and a problem that must be addressed. Government agencies, designers, OEMs, distributors, and integrators can't simply put their heads in the sand. Everyone is accountable for the actions and outcomes of designing COTS solutions into technology, and the military space isn't a place for it to play a significant role."

> "The biggest problem is that the military is using commercial products, which aren't designed for longevity."
>
> – Dale Lillard, president of Lansdale Semiconductor

Fitzgerald acknowledges a need to reduce overall costs, but points out that oversight – in which checks and balances are required – could use some improvement. "Bills of materials, labor, overhead, and costs must all be managed," he elaborates. "Private business could never get away with the lack of discipline and controls that our government shows in its oversight of costs. This is driving the discussion of going to COTS and, frankly, it's a root cause of the issue."

Component and integration designers "are increasingly moving toward COTS in their designs, but with proper planning and requirements – including life cycle requirements – they can be designed into military solutions," Fitzgerald continues.

"Inventory is a 'dirty word,' because companies don't want those costs on their balance sheet. Avnet manages these services and can play a significant role in end-of-life (EOL), life cycle management, and EOL buys to protect our government agencies and their contractors. This involves serialization management tracking, buying lifetime buys for such components, working closely with our supplier partners and customers, as well as mitigating parts so that 'tin whiskers' won't create issues with ROHS (Restriction of Hazardous Substances) parts."

Supply-chain/risk-management challenge

Obsolescence is a huge supply-chain challenge, which is essentially risk management.

"It's very much about risk management and understanding the supply chain," says Abaco's Kirk. "The organizations with whom we work are anxious to mitigate risk throughout the program life cycle – from initial concept through development and testing to deployment. They want to eliminate or at least minimize the impact of risk, whether it's to on-time delivery or cost overrun, and also the risk and impact of component obsolescence is something relatively easy to do."

From Avnet's perspective, "inventory is an asset, not a liability, and provides critical counsel to the military agencies and their primes," Fitzgerald says. "Our approach is to look at requirements and then design upfront solutions that are managed throughout the life cycle so agencies aren't surprised by obsolescence."

Aftermarket suppliers and today's military industry

What role do aftermarket suppliers play in obsolescence management? "Aftermarket suppliers are supporting products that were designed in the 1970s and 1980s – primarily during the Reagan years' buildup. And approximately 80 percent of those systems are still being used," says Dale Lillard, president of Lansdale Semiconductor in Tempe, Arizona. "The F-16, Patriot missile system, and the Navy's Aegis systems are old designs from the time when original component manufacturers had military product lines, and they're still in use today."

Some of the parts being supplied by Lansdale harken back to the 1960s. "Most of the nuclear reactors in the world are using a 600-Series HTL (high-threshold logic) product that was designed in the 60s," says Lee Mathiesen, operations manager for Lansdale. Nuclear power plants rely on it for its "15-V threshold and because it's noise-immune."

Nuclear reactors tend to "raise hell with electronics, so that's why they're still using HTL," adds Lillard. "They're one of our biggest customers. In fact, Westinghouse is still making new controllers using our logic – the entire product family."

Lansdale and Rochester Electronics (Newburyport, Massachusetts) are the two primary aftermarket suppliers to the military – a crucial part of the supply base that the military uses not only for repairs but also for new systems as well. Many of these new systems are for foreign military sales.

"We're still supporting F-15, F-16, and F-18 radars that were designed in the 1980s," notes Lillard. "If we went out of business they'd redesign the system because they'd have to … but it's much more economical for the military to buy products from us."

Obsolescence is a huge supply-chain challenge, which is essentially risk management.

Avoiding obsolescence management missteps

Are COTS vendors who are new to the military market making avoidable obsolescence management mistakes?

"When COTS suppliers obsolete a product, it's extremely important for them to provide a next-generation device that will drop into our designs and that they notify us prior to discontinuance," says Rockwell Collins' Bruns. "The two primary issues we've seen are that some suppliers are unable to provide drop-ins, or when they do we find subtle differences that prevent us from being able to use them."

Avnet's Fitzgerald says he believes that obsolescence management for COTS providers is "counterproductive" because they're "focusing on reducing costs, high rates of flexibility and change, as well as ensuring inventory is available in the channel. The world is moving to the Internet of Things, and 70 percent of the world's market is now focused on COTS solutions, for which clients increasingly lead with software and cloud solutions – leaving the hardware to COTS and agnostic. This is critical for companies who have zero interest in operationalizing their business."

Companies today "are set up with many software engineers, and one within their operations," Fitzgerald continues. "These companies rely heavily on supply chain partners to manage end-to-end solutions – including inventory. The value is clearly software. Military solutions with long lead times and specific market requirements with minimal change allowable and higher mean-time-between-failure (MTBF) requirements don't play well within the market. COTS may play a bigger role, but when it comes protecting our military, my recommendation is do not play with COTS."

The biggest mistake for COTS vendors or newcomers to the military market would be "not having a program in place to offer long-term support and obsolescence management," according to Abaco's Kirk. A COTS product offered by Abaco is the PPC11A. Introduced earlier this year, the board is form, fit, and function compatible with the PPC4A, introduced in 1998, providing a straightforward technology insertion. (Figure 1.)

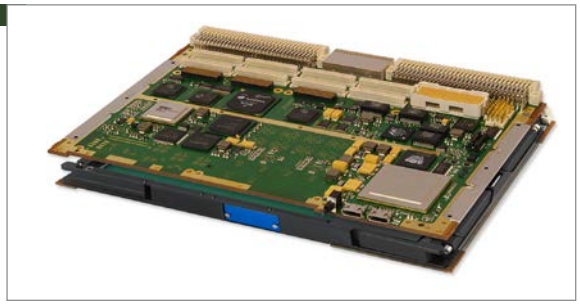


Figure 1 | The Abaco PPC11A is form, fit, and function-compatible with the PPC4A, introduced in 1998.

Current DoD procurement environment

Is the current DoD procurement environment, in which the government largely places the burden for research and development (R&D) investment on the integrators, making obsolescence and product life cycle management more challenging? Yes and no, but mostly yes.

"You can buy a component online with lot control and serialization and ship it within a day," says Avnet's Fitzgerald. "But dealing with government agencies requires a significant amount of scrutiny – some of which is required, yet is unnecessary for other areas. Avnet counsels government agencies by getting inside and in front of these challenges to reduce the overall end-to-end supply chain."

Abaco's customers "increasingly prefer to extend existing programs rather than start a new one," points out Kirk. "This makes a lot of sense because startup costs for new programs can be huge."

For customers who factor in extended programs from the outset, "the cost of providing extended support becomes part of the negotiation because they're trying to minimize their overall cost," he adds. "This, in turn, can shift some of the cost to the supplier.

"Recently, for example, one of Abaco's customers wanted to extend a program for as long as five years for an eight-figure investment, but the condition of placing the order was that the chosen supplier would meet him halfway on the cost of long-term support. At the end of the day, it's a business judgment call we're asked to make. Customers recognize the importance of long-term support – and while it can make selling the concept easier, negotiations can become more complex." **SFF**

UAS payloads, radar best bets for military electronics market

By John McHale, Editorial Director

Demand for modern radar systems such as the Ground/Air Task Oriented Radar (G/ATOR) from Northrop Grumman continues to be steady. Photo courtesy of Northrop Grumman.

"Uncertainty" best describes the current outlook for the U.S. military market, with the next president's positions still somewhat unclear, as is the nation's future defense outlook. Regardless of inertia or doubt in Washington, military program managers and industry engineers must continue to keep the current defense electronics systems in air, ground, and sea platforms running efficiently to ensure continuing military readiness. Moreover, key radar, unmanned, electronic warfare, and other systems must still be modernized. All of this means that opportunities still exist for embedded electronics suppliers.

Sustainment environments in the Department of Defense (DoD) community mean there are few new programs demanding an avalanche of funding; most dollars are targeted to keeping the current systems running via upgrades/modernizations until more funding comes down the road. These modernizations – often for systems such as radar platforms; unmanned sensor payloads; electronic warfare (EW) systems; and command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR) – leverage open architecture designs, say market analysts in the defense industry.

"There have not been any big changes and there are definitely fewer platforms these days," says Brad Curran, Aerospace and Defense Industry Principal at Frost & Sullivan, in an interview before the election. "The FY 2017 DoD budget request was not much different than the year before, where President Obama and his team kind of punted the ball down the field. My guess is that if Hillary Clinton wins it will be more of the status quo and a smaller force and if Donald Trump wins, we will see a pretty sharp spike in Special Operations forces, but will still overall have a smaller force."

Radar

One area that looks to be steady with upgrades and new contracts is the military radar market. "For 2015 there were $2.50 billion in new radar contracts awarded with 64 new awards," Curran says. "This is slightly down from the $2.95 billion awarded in 2015. So far in 2016, through August 15, $821 million in new military radar contracts have been awarded."

Leading the way, as always, "in 2015 was Raytheon, which had $871.5 million in Army, Navy, and Air Force contracts," Curran continues. "Lockheed Martin came in at $426 million in contracts, led by its Long-Range Discrimination Radar for the Missile Defense Agency and the Army's AN/TPQ-53 radar. Northrop Grumman had $480.8 million in radar contracts in 2015 led by its G/ATOR [Ground/Air Task Oriented Radar] work and also the Counter-Rocket, Artillery, and Mortar (C-RAM) Intercept for the Army, which is a neat program as it helps combat small shells and also serves as a counter-unmanned aerial vehicle system. (Figure 1.)

Figure 1
The Lockheed Martin TPQ-53 radar continues to be in demand from the U.S. military. Photo courtesy of Lockheed Martin.

"Boeing also won $340.6 million in 2015 contracts, with the biggest one focused on modernizing the radar systems for the entire F-15 fleet of aircraft," he adds.

Radar, like many other application areas, is not receiving much research, development, testing, and evaluation (RDT&E) attention in the DoD's FY 2017 budget request.

"While funding for radar has not been coming so much for RDT&E, there have been a number of service contracts awarded and there is still quite a bit of procurement happening," Curran notes. "Raytheon continues to sell Patriot radars and is enhancing the Navy's Relocatable Over-the-Horizon Radar. Harris also won a $70 million contract in May from the Navy to provide 42 COTS [commercial off-the-shelf] precision approach radar systems for the Army, Navy, and Air Force. Another interesting radar system in development is Lockheed Martin's Silent Knight terrain following/terrain avoidance radar for Special Operations applications."

China's increasingly aggressive actions in the Asia Pacific region are also forcing U.S. military planners to take a look at upgrading their maritime missile-defense and radar capability.

"Another strong area for radar modernization is in maritime systems, as the U.S. looks to upgrade its missile-defense capability in the Pacific and that of its allies like Japan and South Korea," Curran says. "The Navy also continues to modernize the Aegis Combat System in the fleet, as well as Aegis Ashore. The Navy wants to ensure that their ships in the Pacific can defend themselves against incoming anti-ship missiles."

Radar outlook – long-term

"Looking ahead, how the U.S. deals with laser-based weapons, power-based weapons, and hypersonic missiles from a radar perspective will also be important as our adversaries develop these threats," Curran says.

"A big decision will also have to be made fairly soon regarding the replacement of the Patriot radar, as it is getting pretty long in the tooth," he adds. "There has been system development and incremental improvements to the current system, but some say – to deal with new technology and new threats – it will need to be replaced. It's also not a guarantee for Raytheon that they will win the replacement contract, as Northrop Grumman and Lockheed Martin are going to look to make bids as well."

"Radar modernizations are also opportunities for COTS suppliers, as you have to use COTS on signal processing capability, high-performance FPGAs, and now gallium nitride (GaN) technology, which is becoming essential on the RF and microwave side of radar systems," Curran says.

Electronic warfare

Another military application area dependent on GaN technology and innovations in embedded signal processing is EW.

The total EW funding in the FY 2017 budget request increased to $3.75 billion from the FY 2016 DoD budget request of $2.9 billion, Curran says. "The total number of new contracts awarded for EW in 2015 was 61. In 2014, the EW segment was at about $2.75 billion, with 67 contracts.

"For EW operations, a good bit of funding still goes toward Cold War near-peer adversary operations," he continues. "For example, whenever the Russians overfly U.S. ships they paint us [target the ships with their radar] and we gather electronic intelligence (ELINT) and signals intelligence (SIGNT) data from them. It helps us learn more about the capabilities of their new systems and update our countermeasures appropriately. Counterinsurgency operations are also being supported.

"I'd wish they'd spend a lot more on EW as our adversaries continue to enhance their own EW capability," Curran says.

C4ISR and cyber

Another area seeing an increase in funding is also one embedded-computing companies serve – the C4ISR market and its increased emphasis on cyberdefense.

"I had C4ISR at $43.6 billion in the FY2017 budget, an increase over the $39.54 billion estimated in last year's budget request," Curran says. "One of the big

Counter-UAS market potential

As unmanned aircraft systems (UASs) grow in use for commercial purposes, they are also increasingly used as lethal threats. In response, a crop of counter-UAS systems have popped up to detect, identify, and mitigate or defeat these dangers.

"It is incredible to me how much this nascent market has exploded over the past year," Mike Blades, Aerospace and Defense Senior Industry Analyst at Frost & Sullivan. "We did a market insight on this about a year ago and had about 20 companies serving the counter-UAS market – separated out by defense and commercial. Now there are 60 or 70 companies trying to be a part of this market.

"Many solutions will use technology such as radar, RF components, acoustic microphones, etc.," he continues. "Some companies will use one of those sensors or a mix of them. Some solutions will just leverage a little bit of counter-UAS capability that can deployed to a forward operating base or carried over to airports. There a lot of ideas out there, such as firing nets at the drones, and even one that proposes to use eagles and other birds to take the UAS down."

"We will see a lot of partnerships form to build an effective counter-UAS system," Blades says. "Some that have already organized include Airbus partnering with Dedrone for defense and commercial applications. Blighter Surveillance Systems has worked with Chess Dynamics and Enterprise Control Systems to build what they call the Anti-UAS Defeat System, or AUDS. It is a military-grade counter-UAS system that will leverage RF and EO/IR [electro-optical/infrared] capability and will be able to jam the targets. Liteye Systems is their U.S. partner."

increases was in Operations and Maintenance (O&M) funding for enterprise IT, especially for a defense healthcare network. About 15 to 20 percent of any enterprise network spending is also going to be for cyber – for cyber after the fact or to have more cyber included in a new program. But now the emphasis is shifting to securing networks to securing combat systems.

"The increase in cyber funding is unlikely to subside any time soon, as an inherent portion of enterprise networks for health care, logistics, administrative functions are still important to secure and then you have the additional contracts to plug any holes in these systems," he continues. "Other DoD cyber applications that could be opportunities for commercial companies include cybersecurity for cloud infrastructures and big-data activities. Commercial encryption and cyber is nearly as good as most government technology, so most applications are perfectly fine to use for government-issued mobile devices."

Military communications

Software-defined radio (SDR) technology for military communications systems continues to move forward in development and in fielded equipment, though a bit more slowly than other application areas.

"A radio that can switch back and forth between multiple waveforms is still a goal the government is aiming for, even years after the Joint Tactical Radio System (JTRS) faded away and split up into other programs and nondevelopment items (NDIs)," Curran says. "The technology – SDR – is still too hard to do, so we have to lower operational expectations while continuing to make improvements. We recognize switching simultaneously between waveforms with small radios is not as easy as we thought. To maintain operational reliability, the U.S. is making sure they have separate sets for unique missions.

"Having said that, most of the SDR action today is with Harris and their Falcon family and the FlexNet from Thales," he adds. "One thing for certain is that future radios will have a small-form-factor requirement, with an emphasis on reducing thermals to enable the use of more signal processing. I'm a fan of SDR and see it continuing to be an investment for the U.S. military."

Analysts at Technavio in Elmhurst, Illinois, also see increased requirements driving the global military mobile-computing systems market over the next five years. They forecast the market to grow at a CAGR of more than 7 percent by 2020.

Avionics outlook

"The military avionics market has been kind of quiet with few new starts hogging the attention and most of the money – to be blunt – being spent on the F-35 Joint Strike Fighter," says Wayne Plucker, Aerospace and Defense Director at Frost & Sullivan. "The market has had small negative CAGR even with most spending going toward the F-35.

"When it comes to avionics upgrades, the modernizations that are ongoing are not the wholesale kind of modernizations we've had in past," he continues. "They are

more minor tweaks than anything else. And that is one way of saving money – to temporarily bite the bullet and upgrade only a certain number of systems now, essentially holding your fire until more funding becomes available downstream."

Rockwell Collins and Honeywell are still the leading providers of military flight avionics systems, "but there are a myriad of other computing elements on these aircraft such as mission computers for managing the ISR data on aircraft such as the P-8," Plucker states. Companies such as BAE Systems, Thales, CMC, and GE Aviation contribute in this area as well as in flight systems, he adds.

Figure 2 | The Northrop Grumman Triton MQ-4C unmanned aircraft is still in steady production, according to Frost & Sullivan analysts. Photo courtesy of Northrop Grumman.

U.S. military unmanned aircraft funding

While the commercial unmanned aircraft system (UAS) market gets most of the press attention these days, with the Federal Aviation Administration (FAA) opening up portions of the national airspace to these aircraft, the military market has been more of a sustainment market focused more on payload designs than on new platform designs.

"The market right now is mostly one of sustainment as certain programs like the MQ-9 and the MQ-1C are dropping off in terms of production," says Mike Blades, Aerospace and Defense Senior Industry Analyst at Frost & Sullivan. "Meanwhile, the Triton MQ-4C is still in steady production. Then you have Unmanned Carrier-Launched Strike and Surveillance (UCLASS) aircraft going away and essentially becoming the Carrier-Based Aerial Refueling System (CBARS), which will have similar RDT&E funding levels to UCLASS but be pushed further to the right with regard to spending years." (Figure 2.)

The DoD's funding plans bear this out: "Based on the most recent DoD budget request, FY 2017, U.S. spending will be at about $4 billion for 2015, growing to $6.25 billion by 2021, with a CAGR of about 7 percent," Blades continues. "So we can't ignore a program that size, even if there is a chance it could be another totally manned bomber. If not for the B-21, the U.S. military unmanned aircraft market would be fairly flat through 2021, as the $2.5 billion increase we see by 2021 is all due to B-21. The B-21 is slated for just over $3 billion in RDT&E funding in the FY 2017 budget. These market totals aren't just platforms, but also include sensors, subsystems, and aircraft support and maintenance funding in the full estimate.

"Many of the smaller aircraft still being built are replacements for those lost in battlefield operations or those that have already flown their maximum amount of sorties and are being used for training in guard units," Blades says. "Where you will see growth at the platform level is with the small or micro UASs, but there are not a lot of official programs of record in this unmanned aircraft class. You will see a lot of funding going toward tactical small- and micro-UAS platforms that have medium-altitude long-endurance (MALE)-type capabilities and enhanced sensor payloads."

Payload trends

"Unmanned aircraft funding today is targeting the payloads more than the new airframe designs," Blades says. "It is better and more cost-effective to upgrade the sensor payloads. Whatever may be the platform, the important thing is not flying 30 to 40 hours, it is about increasing the capability of the sensors.

Other analysts also see the sensor payload market as a bright spot. Markets and Markets analysts in Vancouver, Washington, say they estimate the unmanned aircraft payload market's value at $3.63 billion in 2016, and are forecasting it to reach $7.72 billion by 2021, at a CAGR of 16.25 percent between 2016 and 2021.

"From what I know that number is not outrageous," Blades says.

"With any military platform, the smaller you get, the more the percentage of that platform is taken up by payload," Blades explains. "The payload consists of sensors, SATCOM [satellite communications], and data links and with the small ones you're talking about half the cost of a UAS. Even with large platforms, it applies proportionally. If you take the MQ-9 Reaper, 25 percent of it is payload – that does not count the ground-control station or extraneous equipment. For the Army Predator, about 20 to 25 percent is payload."

The question remains whether to process the payload sensor data on board the aircraft and then send it down, or to send the data down first. "The problem with sending the data later is that the data links are not capable of handling all the data being generated," Blades says. "Then when you scramble data and encrypt it, even more space is taken up. A solution to this bottleneck remains elusive. Optical data links, while wide, have to be line-of-sight, as the atmosphere can interrupt the link."

Who is best poised to grab the opportunities in sensor payloads?
"COTS and open architectures are growing in unmanned circles, but there will be areas that are proprietary for classified," Blades says. "I think the bottom line goes back to cost. For sensor payloads today, you need embedded computing on the front end and the back end; there are many companies that can build that capability, but the best will enable that capability in a way that costs less money."

Military vetronics
Over the last few years, the military-vehicle electronics, or vetronics, market has been the most quiet area of the DoD budget. The recent Joint Light Tactical Vehicle (JLTV) award to Oshkosh Defense did add some minor excitement to it last year, however. (Figure 3.)

"The military vetronics world is still quiet, even with the JLTV being alive and well," Plucker says. "There is still refurbishing going on for Foreign Military Sales and also upgrades happening, based on lessons learned in battle. We took some platforms in Iraq that we were able to make adjustments to in the field, but some need long-term fixes such as enhancements to situational awareness and improvement in power distribution.

"There are also some vehicles that will never be retrofitted, as they've been worn out, but there are some lightly used platforms that may have be around for many years," Plucker continues. "Stryker [armored combat vehicle] is a good candidate to last, as it probably has better legs than some other vehicles. Much of the work on military vehicles is low-level right now, as the revenue in this market segment is barely moving. Realistically, until the next president takes office and sets an agenda with a new Congress, we won't get a clear picture on ground-vehicle funding."

JLTV
"The JLTV getting life was a surprise to some and is kind of a neat opportunity," Plucker says. "It's just that the JLTV won't be a target-rich environment for the proliferation of computing systems because it's the jeep of the military world. As we start using the JLTV for special missions and such, we will see folks like DRS and BAE Systems having more to do in this area. But the initial JLTV investments will be to see if the vehicle works properly." **SFF**

Figure 3
The Joint Light Tactical Vehicle (JLTV) award to Oshkosh Defense in 2015 was big news in the military vetronics community. Photo courtesy of Oshkosh.

ARMed and ready

By Ross Bannatyne

High-reliability integrated circuits must be guaranteed to work in extreme environments, like those found in space. Photo of the International Space Station courtesy of NASA.

While the rest of the engineering world has been developing embedded systems using the ARM microcontroller unit (MCU) architecture for many years, the high-reliability (hi-rel) market has been slow to adopt it. That is a pity because the biggest benefit of using an ARM-based microcontroller is the ease of development that ARM offers, by virtue of the large supporting ecosystem of tools.

One reason for this slow adoption of ARM-based microcontrollers is that suppliers of these MCUs have been even slower to embrace the requirements of the military and aerospace design community. High-reliability (hi-rel) integrated circuits (ICs) need to be guaranteed to operate in extreme environments such as extreme radiation or temperature. It consumes considerable resources and budget to develop and qualify chips that are guaranteed to operate in such environments – frankly, it is easier for the semiconductor suppliers to play it safe by developing chips that will sell in higher volume in consumer applications.

Engineers are trained to solve problems: The lack of availability of hi-rel ARM microcontrollers has not stopped these engineers from doing their jobs and creating hi-rel military embedded systems anyway. Today there is a limited pool of components, often very mature products, that will get the job done, although it may not always be pretty. Field-programmable gate arrays (FPGAs), digital signal processors (DSPs), and legacy microprocessors are often used in embedded systems for the simple reason that they have already been qualified to military spec and that they are trusted and proven.

Power consumption is another major benefit of using microcontrollers, particularly ARM. Because battery-powered systems have been a big driver in the embedded market for many years now, microcontroller architectures have evolved in response to the low-power requirement.

places to go for help to ask a question, find a software driver or a communications stack that is already available, or get technical support. Training is also included in the ecosystem – either bringing a professional trainer into your facility for a day or two, or going to YouTube to watch a video.

What do MCUs bring to the party?
Now that there are options available for rad-hard and extreme temperature ARM Cortex-M based microcontrollers, embedded systems designers can choose the most efficient solution to the problem. There are quite a few benefits of adopting an ARM-based microcontroller, the biggest one being the supporting ecosystem.

The ecosystem for a microcontroller covers many aspects, the most obvious being hardware and software development tools. There exist lots of options from freeware, from cheap and cheerful all the way up to professional-grade tools that cost real money. The ecosystem also encompasses the community – the

The ARM CPU and instruction set were designed for embedded-control applications. The core is efficient for monitoring incoming data, processing it with math-intensive routines (such as digital filtering on noisy data from sensors), and managing on-chip peripherals that interface to external chips, sensors, and actuators. Most embedded designers that are starting a new design with a blank sheet of paper would probably be expected to start with an ARM microcontroller. The benefit is not just realized in the initial design, but it actually greater in subsequent designs, because the code is reusable. Often a few tweaks to the known good code and some additional routines are all that is required for spin-off or development of next-generation systems. Contrast that ease of use with FPGAs, which are more expensive, are more difficult to design with, have a smaller existing ecosystem than the MCU, and do not offer the same level of reusability as the MCU.

Power consumption is another major benefit of using microcontrollers, particularly ARM. Because battery-powered systems have been a big driver in the embedded market for many years now, microcontroller architectures have evolved in response to the low-power requirement. Operating current consumption with ARM is typically less than a tenth of that of an FPGA, DSP, or application processor. Moreover, standby current (when the CPU is not executing but nonvolatile memory contents are maintained and the core will wake up instantaneously in response to an interrupt) is significantly lower.

Hundreds of different ARM-based microcontrollers are available today, covering almost every conceivable combination of on-chip peripherals, pin count, and memory size option. There are also now many different ARM CPUs in the Cortex-M class (the range that are optimized for embedded applications) to choose from. Fortunately, these CPUs have the same look and feel as well as a high degree of compatibility. The higher performance cores typically have more functionality but retain backward compatibility. Not all of these products are a great fit for military embedded systems; in fact, not many of them are. The good news: A growing number of MCUs have been designed for hi-rel applications and it is now possible to take advantage of the ARM ecosystem.

What makes a hi-rel ARM MCU?

Figure 1 is a block diagram of a hi-rel microcontroller based on ARM Cortex-M0. The IC has a combination of "standard" ARM peripherals such as serial communication interfaces (SPIs, UARTs, I²Cs) and counter/timers (for PWMs, etc.) as well as "hi-rel application"-type features.

The hi-rel features that are now available on this class of chip start with enhanced wafer fabrication processing to immunize against latch-up in the presence of radiation or extreme temperature. In addition, all internal registers have been implemented with triple modular

redundancy (TMR). Both of these attributes are invisible to the firmware programmer but are critical to the system design.

On-chip peripheral hardware enhancements include an on-chip error detection and correction system with a scrub engine that can automatically correct flipped memory bits. This feature has been included to ensure that the memory operates reliably in the presence of ionizing radiation particles. Note that while the TMR also protects the chip against ionizing radiation, the chip is designed to protect the logic and circuit routing rather than the memory cells.

Along with integrating processing enhancements and hi-rel type peripherals, the packaging options are optimized for extreme environments. Figure 2 shows a PCB that has been developed for a space application – the PCB is located on the International Space Station. Right in the center of the board is an ARM Cortex-M0 based microcontroller in a hi-rel ceramic package.

A robust MCU that doesn't cost an ARM and a leg

The good news is that after years of watching the ARM microcontroller world blossom into a treasure trove for embedded designers, there are finally products being developed for hi-rel environments such as military end uses. It is now possible to take advantage of the benefits that these offerings bring to embedded designs while conforming to the hi-rel specification. It is still true that ICs that are designed for USB sticks are not suitable for defense systems; in this spirit, designers must still choose carefully.

Why are these chips just now being developed? There is a demand for a higher volume of reasonably priced processor products such as ARM Cortex-M microcontrollers to support new growth applications such as megaconstellations of small and picosatellites. These applications need components that are sure to work in extreme environments but cannot have the high price of traditional space/mil FPGAs. These demands are driving the development of this new class of hi-rel ARM microcontrollers. **SFF**

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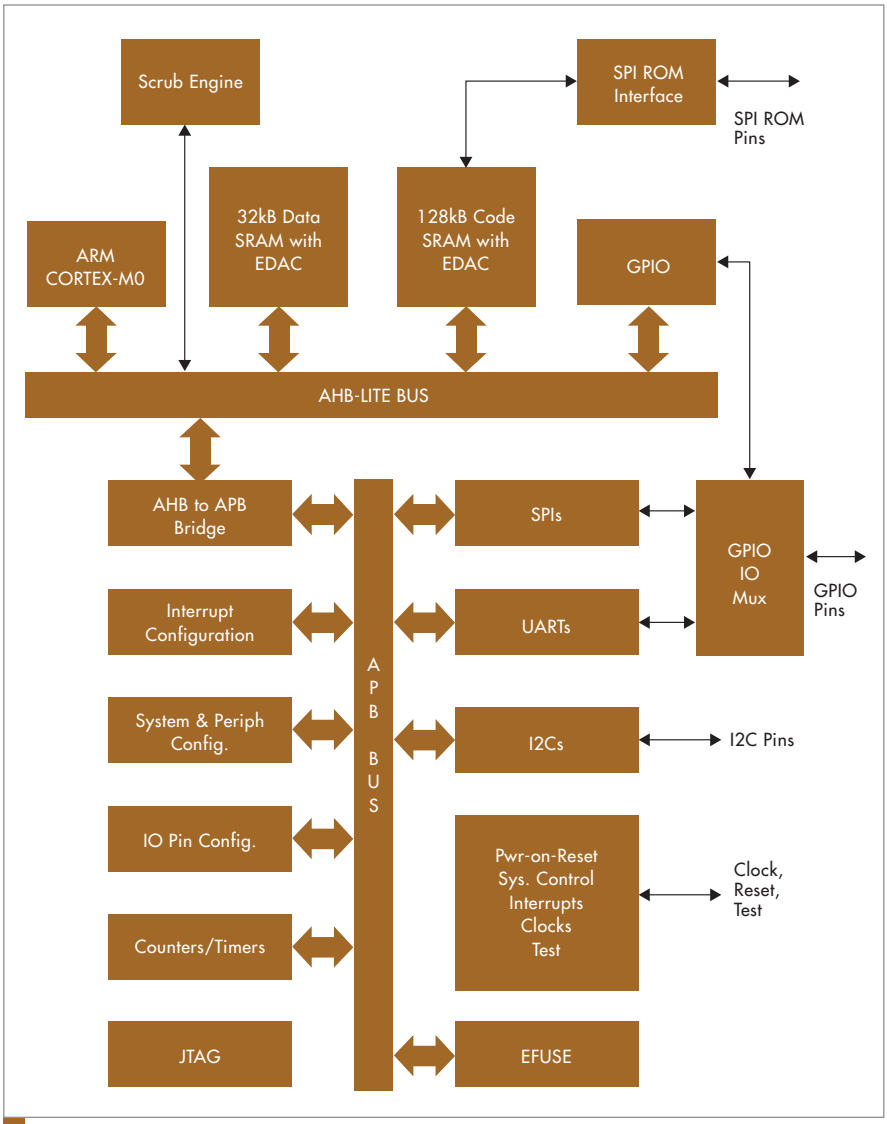

Figure 1 | Block diagram of ARM microcontroller intended for hi-rel embedded applications.

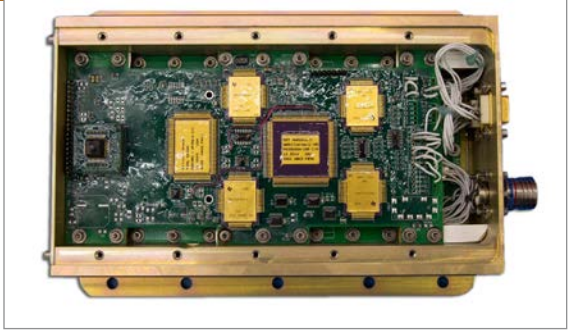

Figure 2
Hi-rel embedded system using ceramic packaged ARM-based MCU. Image courtesy Vorago Technologies.

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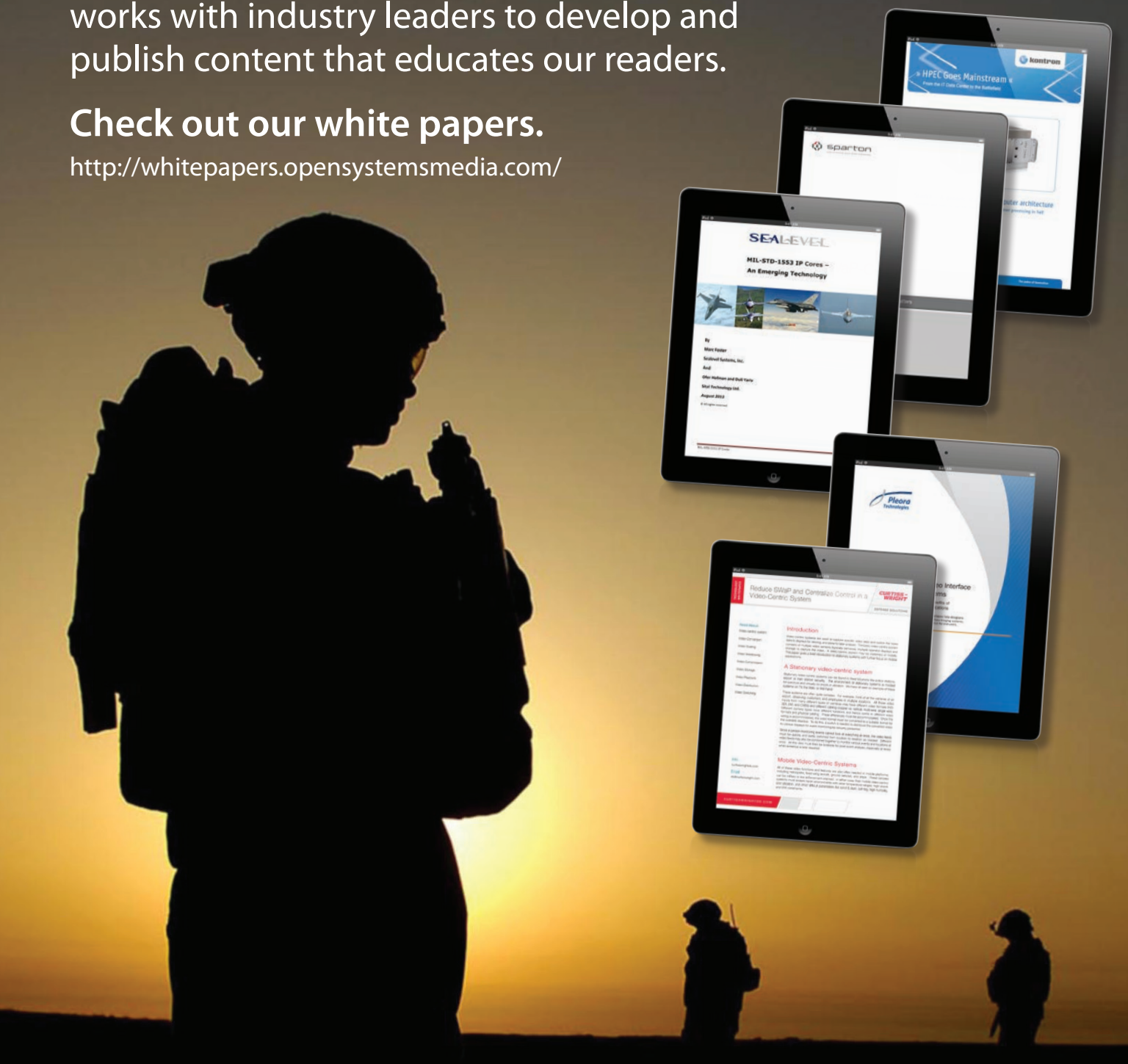

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