Raytheon

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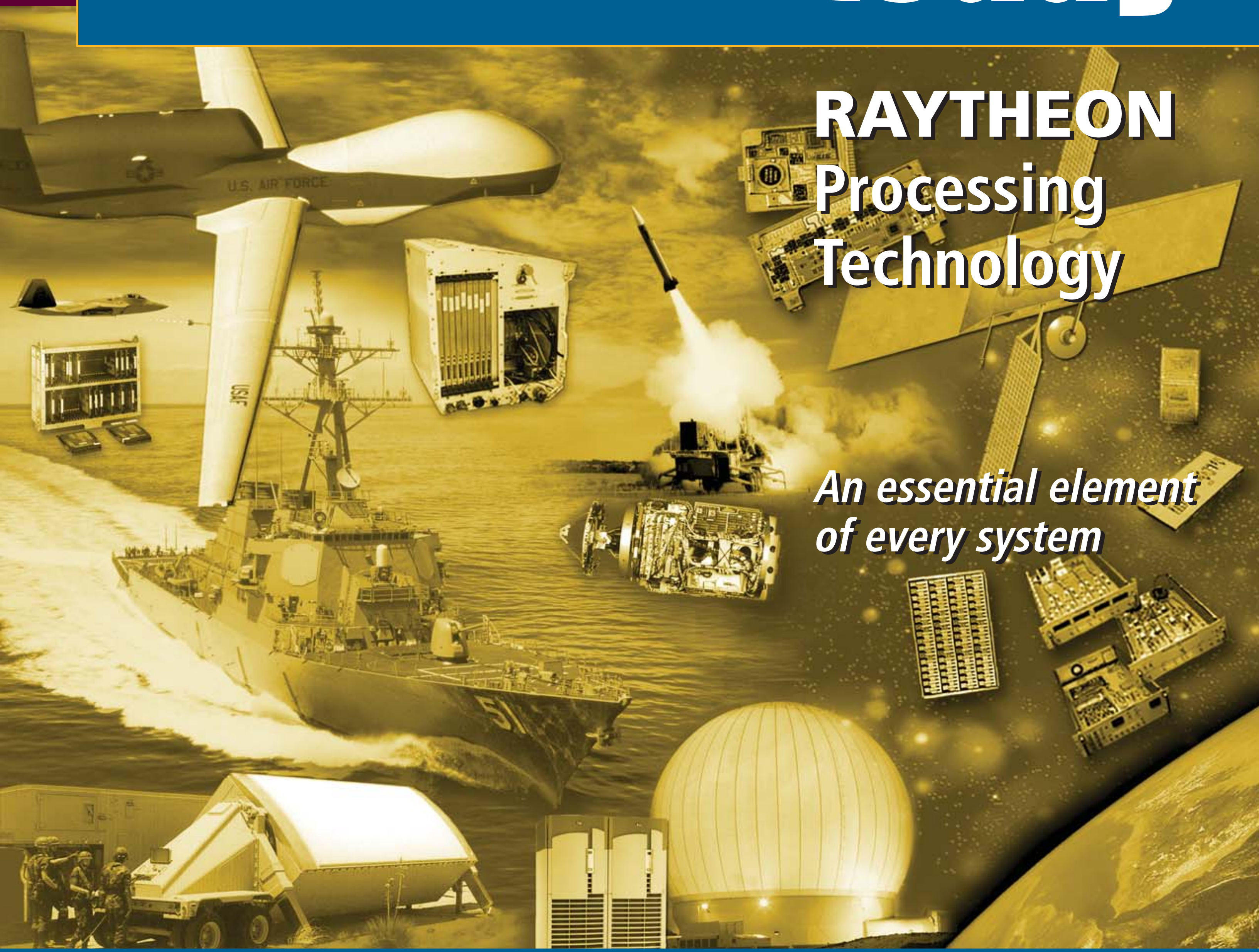
technology today

HIGHLIGHTING RAYTHEON'S TECHNOLOGY



RAYTHEON Processing Technology

An essential element of every system

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A Message from **Greg Shelton**

Vice President of Engineering and Technology

In this issue of technology today, we are highlighting processing technology at Raytheon. The objective of these overview articles is to expose you to the broad range of processing systems and technologies that Raytheon is employing today and developing for the future, which will enable us to continue delivering world class solutions to our customers. Critical to Raytheon's success is technology, tools, process and most importantly, the people that use them. Leveraging a rigorous mature process deeply rooted in IPDS, CMMI and Raytheon Six Sigma, while exploiting a One Company approach, and proactively garnering strategic CRAD opportunities will afford Raytheon the opportunity to continue to deliver quality solutions well into the future.

On a lighter note, I was very excited about this issue because I can relate to it from a personal perspective. More than 30 years ago, I began my career working on leading edge processing technologies. We developed a bit-slice special purpose processor running in kilo-flop speed domain. Our assembly instruction set was developed in microcode. We were thrilled to have a 100 instruction set assembly code with 16K of memory. This digital signal processor had an FFT that used custom hardware specific processing running in conjunction with the bit-slice processor. The next generation hardware had to interface with the microcoded instruction set due to the cost of software conversion.

Things have dramatically changed.

Today, we are talking about tera-flop processing across a loosely distributed network. We are driving towards software architectures that are hardware agnostic. We are using middleware to enable portability of software for downstream hardware upgrades and re-use of software from system to system.

Processing has penetrated all aspects of our products and life. Take a look around us today and we see software in almost all products we use on a day to day basis. Our systems' complex functionality is implemented in millions of lines of code developed in a modular form that enables re-use and upgradability.

Moore's Law continues to drive processing capabilities that we exploit by providing greater functionality to our customers. Think about how our systems will exhibit the cognitive, autonomous behaviors enabled through higher powered computing capabilities. As we move processing power closer to the front end of our systems, we make our systems more adaptable and flexible while reducing costs. We are driving closer and closer to the antenna face. We are processing raw data from our sensors and delivering information to the user.

I hope this issue brings you some interesting insight into our processing technology capabilities—an example of our technology excellence. Raytheon — we just keep getting better!

Sincerely,

Greg

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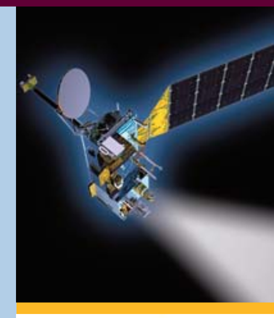

EDITOR'S NOTE

Two things came to mind as we began to put together this issue of technology today: one was the depth of our technology and the other was the greatness of our people.

It is the pursuit of excellence that has made our company great. Our story on page 22 is about the 2002 Distinguished Level Excellence in Technology awards celebration held at the Smithsonian Air and Space museum. It was an honor to be a guest at this ceremony celebrating technical excellence at Raytheon, to be surrounded by our leaders in technology, in a venue where so many had accomplished what many said would never happen. As engineers, we turn ideas into reality. Many of these ideas are making a difference for our armed forces and the world at large. As John Scully, former CEO of Apple Computer and Pepsi stated, "The future belongs to those who see possibilities before they become obvious."

It is hard to convey in a publication like this one the importance of working as One Company, making optimal use of our available resources, enabling us to excel by providing superior solutions to our customers. That is the mission of the Engineering & Technology Council (E&TC) as described on page 26. Our engineering and technology leaders comprise this council and are committed to working together, sharing best practices and knowledge — take a moment and learn about the council and its leaders.

As always, I welcome your feedback, ideas and One Company success stories.

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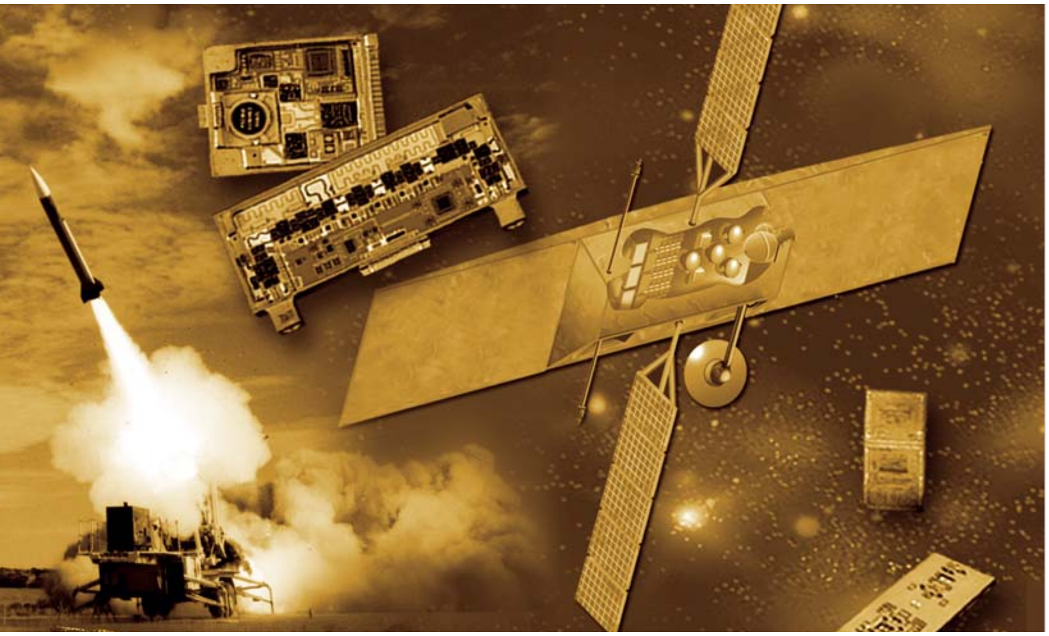
Raytheon Processing Technology

an essential element of every system

Overview



What capability is a crucial part of virtually every Raytheon system? As our systems grow in complexity and performance, one technology that is increasing in importance is processing.

Not processing in the sense of our factories where we "process" circuit boards or subassemblies into finished systems, but the processing of data inside our systems to create information. Extracting, correlating and presenting this information for the users of our systems requires many system, hardware, and software technologies.

Historically, processing has been broadly grouped into two categories: signal processing and data processing. Signal processing converts raw sensor data into useful information. Data processing uses information provided by signal processing and by human operators to make decisions and control systems, thus accomplishing mission objectives. Signal and data processing are at the heart of our systems, making sensors into useful systems that enhance human capabilities, whether that be flying an aircraft, navigating a submarine, locating potential threats, destroying an enemy missile, or myriad others.

This paradigm is changing with the emergence of a new type of processing called "cognitive computing". Going beyond classical data processing, cognitive computing is defined by the Defense Advanced Research Projects Agency (DARPA) as a processing system that can "reason, use represented knowledge, learn from experience, accumulate knowledge, explain itself, accept direction, be aware of its own behavior and capabilities as well as respond in a robust manner to surprises." Cognitive computing is strongly supported by DARPA[1] and by commercial computing companies such as IBM, with their Autonomic Computing initiative[2]. This technology may become a key discriminator for future Raytheon processing systems, allowing us to more efficiently develop new and more complex functionality, field systems that automatically handle unexpected inputs in an optimum manner, and work as seamless extensions to users to become force multipliers.

The Processing Technology articles in this issue were compiled by Raytheon's Processing Systems Technology Network (PSTN) leaders: Lou DiPalma, Gillian Groves, Bill Kiczuk, Bruce Kinney and Mike Vahey.

Gary Beene, Charles Channell, Jim Conway, Russ Dube, Tony Laviano, and Jeff Wagner from Raytheon, Dr. John Bay from DARPA IXO, and Dr. Douglas Schmidt from Vanderbilt University also contributed to the processing technology content of this issue.

	Today	Future (5-10 years)
Architectures	• Platform centric • Stovepiped/Isolated • Opportunistic reuse with limited attention to architecture design	• Network centric – much more capable together than alone • Interoperable • Strategic reuse based on product line architectures • Model driven architectures
Hardware	• Custom hardware for harsh environments • Ruggedized COTS in some environments • Single processor per die • RISC and superscalar processors • Specialized coprocessors for high throughput processing	• Increased use of ruggedized COTS hardware appropriate to the environment • Continued use of custom hardware for extreme performance, harsh environments, security, and possibly cost • Multiple processors per die • Multithreaded processors • Reconfigurable processors
Software	• Application specific libraries • Multiple emerging communication and object infrastructure standards • Unique operating systems for embedded realtime software • Security emerging as a serious issue	• Component based software • Standard object infrastructure • Pervasive use of open, standard middleware • Cognitive, intelligent agents • Model based design & code • Quality of service concerns (e.g. real time, fault tolerance, security) modeled and implemented separately from functional capabilities

Table 1. Future Processors will benefit from maturation of today's technologies

Rapid advances in processing technology are enabling new processing paradigms, such as cognitive computing. Processing in past systems was performed by dedicated analog or digital electronic hardware. Today, most processing is performed by multiple digital processors, operating under software control. Over the past twenty years these digital processors have increased in throughput while the software has increased in sophistication. In the future, new processor types such as optical, molecular, quantum, or biological may emerge, enabling a new era in system functionality. Today's digital processors are pervasive, yet the associated technologies have yet to reach their full potential. Table 1 shows where key processing technologies are expected to go over the next five to ten years. Keeping up with these rapidly evolving processing technologies is one of Raytheon's major thrusts.

The throughput requirements of a system's software applications drive the number of processors and interconnect structures in the hardware architecture. Raytheon successfully deploys a broad range of processing architectures to meet a diverse set of application requirements, including:

- Tightly coupled systems arranged as symmetric multiprocessors, such as our missile defense radar, ship defense radar (see sidebar, SPY-3 Radar, page 8), and other ground-based radar and imagery processing systems,

Highlights

Raytheon's Processing Capabilities

Space Tracking and Surveillance System

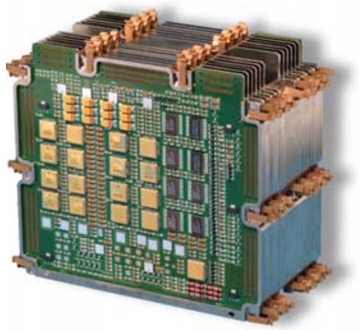
The STSS processor is an excellent example of meeting harsh and constrained physical system requirements to achieve a robust, high performance, low power processing system. The resulting processor uniquely meets this program's needs, but performs its role with only 145 watts. This compares to a commercial processor that would require 10 times more resources and wouldn't have the radiation tolerance or the fault tolerance.

Challenges

- Multispectral processing
- On-orbit detection of missiles against clutter background
- Harsh radiation environment
- Low power and weight for 20 GOP processor
- Input rate 2.2 gbits per second — equivalent to reading an entire encyclopedia six times every second

Methods and Technology Applied

- Developed and refined computationally efficient detection and tracking algorithms
- Developed 6 custom ASICS all with first pass success
- Used radiation hardened RAD6000 processors with supporting COTS software development environments
- Fault tolerant computing design



Highlights

Raytheon's Processing Capabilities

F/A-22 Common Integrated Processor

The CIP is an excellent example of Raytheon's ability to design and field a flexible militarized programmable integrated processing system. The CIP hosts software applications developed by nine geographically dispersed DoD contractors for the F/A-22's integrated Radar, communication/navigation/identification, electronic warfare, and mission management systems.

Challenges

- Heterogeneous processing resources including embedded crypto
- Real time muli-level secure computing
- Single point fault tolerance—sustain full mission functionality in the presence of any single fault, provide degraded mode operation with two or more faults.
- High availability
- Two level maintenance
- Long >20 year mission life
- High functional density, low power and weight

Methods and Technology Applied

- Architecture design, simulation, and verification
- Developed 17 custom ASICs (11 for CIP 2K) with rapid re-synthesis for technology growth
- Based on Intel processor i960MX processor with upgrade transition to Power PC
- High density packaging using liquid flow through SEM-E modules and multi-chip packages
- Developed high reliability and multi-level secure operating system (AOS). A spin off version is now available for other platforms
- Developed an Ada software development and debugging environment integrated with the Air Force's ADS S/SEE

PROCESSING TECHNOLOGY (continued)

- Large distributed systems with hundreds of loosely coupled processors, such as many of our ground-based mobile sensor systems, submarine combat systems, or airborne reconnaissance systems (see sidebar, Combat Control System Mk2, page 9),
- Compact, closely coupled embedded processors consisting of a small number of independent processors connected by a high bandwidth, low latency interconnect fabric, such as our missile or satellite systems (see sidebar, Space Tracking and Surveillance System, page 5),
- Hybrid systems integrating techniques from different types of systems to best meet an application's needs, such as many of our airborne sensor and avionics processing systems (see sidebars, F/A-22 Common Integrated Processor, page 6, and Global Hawk Integrated Sensor Processor, page 7) or manportable sensor systems.

As our systems get more complex, software development is increasing in importance because much of the system's functionality and complexity is embedded in the software. Our challenge is to deliver this increased functionality without a proportionate increase in the software development effort — through increased software productivity. We are meeting this challenge on two fronts — process and technology. Our software engineering organizations, using Raytheon Six Sigma and the best practices of industry, are rated as mature and innovate organizations, which are the highest levels of the Capability Maturity Model® (CMM) developed by the Software Engineering Institute (SEI). Recognizing the importance of integrated processes, all our functional organizations are working together to mature our processes using the Capability Maturity Model Integration (CMMI). These thrusts will benefit every Raytheon system development effort.

Developing the increased levels of functionality being demanded of tomorrow's systems requires more than having a mature development process. It requires applying the right technologies — hardware, software, and systems — in the right places. We work with DARPA and other external technology developers advancing technology to meet our unique challenges. We use our Discipline Engineering and Technology Councils and Technology Networks[3] to ensure the "best" technology is available to projects throughout Raytheon. We will discuss some of these efforts throughout this issue.

Architectures Support Technology Evolution

We constantly challenge ourselves to develop and deploy systems faster and more affordably. Meeting this challenge often requires us to exploit capabilities developed elsewhere by integrating these capabilities into our systems. Frequently we re-use capabilities that Raytheon has developed for another purpose by modifying and adapting them to a new mission or environment. Increasingly, we integrate commercial off-the-shelf (COTS) hardware, software, or algorithms developed by third parties with our own technologies to quickly and affordably deliver functionality to our customers. When we have to rely on technologies developed for commercial applications, where product life cycles are measured in months, and apply them to systems with life cycles of many years, we face new challenges in development, testing, fielding, and supporting our systems.

A robust system architecture is key to effectively integrating products developed elsewhere into new capabilities. A robust system architecture provides the framework for integrating the right hardware and software from diverse sources into a coherent and effective new capability. A robust system architecture also provides a means to harness rapid growth and change inherent in the underlying commercial products.

These issues are discussed in more detail in the article on product line architectures on page 10.

Raytheon's processing systems are as varied as the systems we produce. This variation is in both form and function and has led to a broad array of technologies and architectures. System architecture views incorporate and integrate both hardware and software architectures, even though we often think about them separately.

Hardware Architectures Address Unique Environmental Requirements

Besides long system life cycles, our customers have many other unique requirements not faced by commercial applications. Not the least of these is the harsh environments that many of our systems must operate in, including hot deserts for many systems, high shock loads in a missile, humid and corrosive environments aboard a ship, or bombardment by cosmic rays in space, to name just a few.

The environments in which the system must operate and the throughput demands of the application largely determine the hardware architecture. In many systems the primary challenge is to fit a large amount of processing into a small, constrained location. This class of system exploits advanced packaging technologies. On the other end of the spectrum are systems that have the luxury of operating in relatively benign environments. Figure 1 depicts this range of systems and environments.

Raytheon develops the processing hardware and packaging technologies required to address our customers' unique performance and environmental requirements. Our past efforts and future plans in this area are discussed in the article on processing hardware technologies on page 13.

Figure 1. Raytheon applications demand a wide range of processing solutions.

Highlights

Raytheon's Processing Capabilities

Global Hawk Integrated Sensor Processor (ISP)

The ISP illustrates the innovative use of COTS and how Raytheon works with a COTS processor supplier to enhance their product to meet DoD mission needs.

Challenges

- Highly parallel processing (153 GFLOPS peak throughput) with large memory, low latency, and high interconnect bandwidth requirements
- Commercial processing hardware in an airborne platform
- High speed I/O - >90 MB/sec
- Software migration from legacy processors

Methods and Technology Applied

- Architecture design and rapid prototyping
- Scaleable, parallel processing – total of 48 PowerPCs
- COTS ruggedized processor boards (stiffeners, conformal coating, air impingement cooling)

Highlights

Raytheon's Processing Capabilities

SPY-3 Radar

The SPY-3 radar signal and data processor is an excellent example of using commercial processing technology to address defense system requirements. SPY-3 is the Navy's next generation ship defense radar system. The system uses a commercial general purpose high end server to perform real time signal processing. Advanced signal processing algorithms — such as pulse doppler, real time range/doppler images, and multiple hypothesis tracking — combined with multiple receiver channels and support for multiple simultaneous radar functions — search, track, and engagement support — make the SPY-3 radar processor one of our most challenging processing systems.

Challenges

- Long life cycle – 20 or more years
- Low latency requirement — rapid sensor-to-shooter loop closure
- Signal processing throughput efficiency — 40% sustained to peak operations
- High degree of software portability for upgrades and derivatives

Methods and Technology Applied

- Commercial IBM Regatta series symmetric multiprocessor (SMP) servers, ruggedized for the shipboard environment, provide the computing throughput and high productivity software engineering environment
- CORBA based communication infrastructure provides a portable command-and-control user interface
- Universal Modeling Language (UML) provides a robust design environment and methodology, resulting in an adaptable and flexible design
- Object Oriented Design instantiates modern software technology for increased productivity
- ACE/TAO COTS common operating environment (COE) provides processor platform vendor independence through open standards compatibility

PROCESSING TECHNOLOGY (continued)

Software Architectures Address Many Functional and Performance Requirements

Software architecture is driven by function, performance, and life cycle requirements. Many weapon systems have tight deadline tolerances, and the system timelines are such that these deadlines are the primary design concern. These are the *hard real-time* systems that often demand special architectures to guarantee performance. On the other end of the spectrum are the more transaction-oriented systems that have softer timeline requirements. Often these latency and determinism requirements combined with the inherent speed of the processing system is what drives the software architecture and dictates which technologies and architectures are feasible for the system. In the book "Doing Hard Time," Bruce Douglass[4] defines real-time systems:

"By definition, real-time and embedded systems control and monitor physical processes in a timely fashion. They must operate under more-severe constraints than "normal" software systems and yet perform reliably for long periods of time. Some of the constraints are inherent in their problem domain, such as schedulability, predictability, and robustness. Other constraints come from the need to reduce recurring system cost by cutting the

Environmental /Physical Constraints	**Hard** Guaranteed Timing	**Buffered** Processing must be kept up. Longer latencies acceptable	**Fast Enough** Processing fast enough. Latency not a concern	**Non** Off-line System with no deadlines
Severe Constrains Solution Space	Projectile Guidance and Control	Missile or Space-based Sensors	Space-based Communications	Space-based Off-line Processing
Medium Concern, but System Adapts	Vehicle or Avionics Based Fire Control	Vehicle or Avionics Based Sensors	Portable HCI and Communications	Portable Command and Control
None Environment Adapted to System	Ground Installation Tracking and Fire Control	Ground Installation Based Sensors	Ground Installation HCI and Communications	Ground Installation Mission Planning

Real-Time Constraints

Figure 2. Raytheon systems meet a wide range of operational requirements

amount of memory or capability of the processor. Most real-time and embedded systems must operate with a minimum memory footprint and with a minimum of support hardware. Taken together, these constraints greatly complicate the development of such systems."[4]

As this definition suggests, system development is complicated by two factors: (1) environmental/physical constraints discussed earlier and (2) real-time constraints. As shown in Figure 2, Raytheon's systems span the entire range defined by these two factors. A rich portfolio of hardware, software and systems technologies enables this unparalleled breadth in systems.

Our challenge for future processing systems is to use architectures that evolve and scale gracefully, therefore accommodating new performance requirements without re-architecting. Our involvement with DARPA in programs such as Adaptive and Reflective Middleware Systems (ARMS) and Program Composition for Embedded Systems (PCES) is addressing this challenge. These efforts are described in the article on software technologies on page 15. Interviews with two of our DARPA customers in this area, Dr. John Bay and Dr. Douglas Schmidt, also found in this issue on page 18, shed additional light on our shared vision for the future of software technology.

In this environment of challenging customer requirements, shorter cycle times, reduced cost, and rapidly changing technology, we must work together as One Company to apply the most appropriate technologies to the challenges we face. We must apply existing products and technologies where appropriate, and adapt them if necessary to meet our customers' requirements. We cannot afford to "re-invent the wheel" when faced with similar challenges in different segments of the company. Not only must we "do it right" on each individual program, but we must apply our successful techniques and technologies over and over again to meet similar challenges on all our programs. We are meeting this challenge, using tools like Raytheon Six Sigma, the Integrated Product Development System (IPDS), CMMI, the Discipline Engineering and technology Councils, and the Technology Networks. In the remainder of this issue, we will show how Raytheon is addressing the challenges presented by the need to quickly and affordable provide increasingly capable systems.

– Bill Kiczuk

Bill Kiczuk is Raytheon's Technology Area Director for Processing Technology.

– Bruce Kinney

Bruce Kinney is the facilitator of the Processing Systems Technology Network and manages processing related technology efforts in the Software Engineering Center for Integrated Defense Systems

[1] Testimony before the Subcommittee on Emerging Threats and Capabilities, Senate Armed Services Committee, Dr. Tony Tether, DARPA Director, April 10, 2002, http://www.darpa.mil/body/NewsItems/pdf/DARPAtestim.pdf

[2] IBM Autonomic Computing, http://www.ibm.com/autonomic/index.shtml.

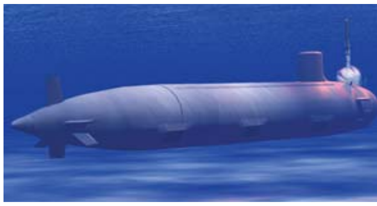
[3] Raytheon Engineering & Technology Councils, Networks, & Teams, http://home.ray.com/rayeng/councils_ntwk_teams/index.html.

[4] Douglass, Bruce Powell, Doing Hard Time – Developing Real-Time Systems with UML, Objects, Frameworks, and Patterns, Addison-Wesley, 1999.

Highlights

Raytheon's Processing Capabilities

Combat Control System Mk2 AN/BYG-1(V)



The Mk2 subsurface combat control system (CCS) is another excellent example of leveraging commercial hardware and software technology to produce a flexible and evolving system. Mk2 is the Navy's system of choice for subsurface combat systems. Mk2 employs commercial general-purpose servers and workstations to host an integrated system comprising Raytheon, GFE and CFE products. Open system standards and open source infrastructure facilitate sensor and contact management for disparate subsystems aboard the submarine. Common core applications are combined with embedded firmware to provide weapon and launcher control.

Challenges

- Heterogeneous computational nodes
- High availability with automatic failover/recovery actions
- Weapon alignment senescense accuracy requirements
- Large number of disparate interfacing subsystems
- High degree of software portability for hardware technology upgrades and advanced processor build components
- Maximizing common system components across multiple hull configurations

Methods and Technology Applied

- Commercial HP and Intel symmetric multiprocessor (SMP) compute nodes provide distributed processing environment
- CORBA interfaces standardize communication to disparate subsystems
- Open source middleware ensures data integrity and node failover for high availability
- Focus on common requirements and flexible open software architecture
- Industry standard protocols and services such as SNMP and NTP
- Significant use of COTS software with active monitor for migration and upgrade
- ACE/TAO COTS common operating environment provides processor platform vendor independence through open standards compatibility

Product Line Architectures (PLAs) enable strategic design product re-use across a range of applications. These architectures are the right solution for today's systems and future systems because software has become endemic, often representing the single largest cost of processing system development. Raytheon excels at building high technology and complex systems. We typically produce families of similar products that individually have different specialization or application-unique features. The platforms in which these products and systems are hosted have long life times, during which the software and processing system hardware are expected to evolve to incorporate new technologies and provide additional functionality. One way to reduce the cost of software development in these systems is to adopt a policy of strategic reuse: a product line architecture strategy.

Raytheon has been implementing domain-specific product line architectures for almost two decades; during which time the cost savings and cost avoidance have been significant. As our systems become more complex, interoperable, and network centric, it is imperative that we expand the use of product lines throughout our product portfolio in order to become more cost effective and agile in responding to rapidly evolving customer requirements.

Definition of Product Line Architecture

Product Line Architectures are not a unique Raytheon invention. They have been applied successfully in numerous applications across industry. The Software Engineering Institute (SEI) provides the following definition for product lines, which share a common architecture:

A software product line is a set of software-intensive systems sharing a common, managed set of features that satisfy the specific needs of a particular market segment or mission and that are developed from a common set of core assets in a prescribed way.[1]

Generic requirements are defined for the core components that will comprise the product line. Specific implementations will pull from the core product line repository. Product line architecture concepts are being applied successfully at both a low level, building upon a limited number of generic core components, and a high level, with a more formally defined architecture.

activities within the specific domain. Exploiting a product-line architecture approach requires diligence in system/software architecture; appropriate component coupling and cohesion, software requirements management and derivation, software development tool-suite environment as well as appropriate product-line architecture software configuration management.

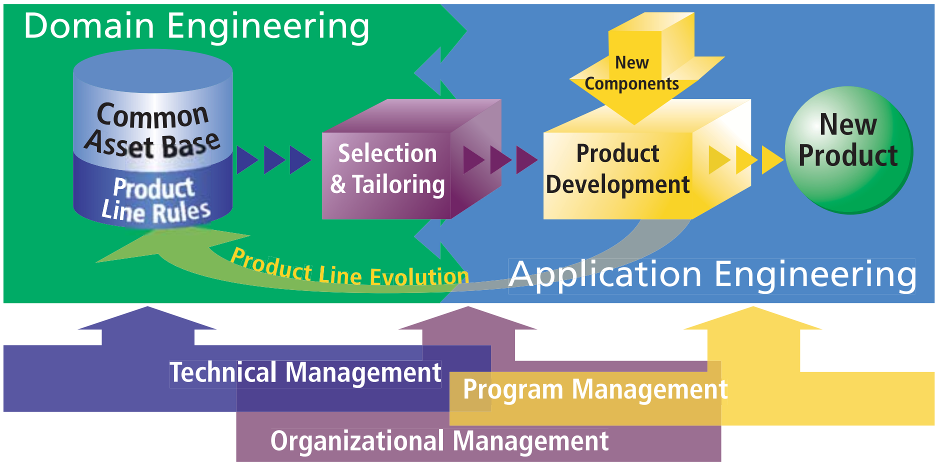


Figure 1. Product lines require both domain and application engineering, and management support throughout the lifecycle.

Determining the breadth of the "product line" and the potential reuse across the product line are critical first steps in quantifying the potential benefits of a product line approach. A product line may be defined in two dimensions: (1) application of common components across different products, and (2) evolution of components with time. The first dimension allows functionality to be re-used across multiple systems and built up over time. The second dimension is particularly important for more of our systems; it explicitly addresses how evolving technology will be inserted into long life systems.

At its core, application of product line architectures forces designers away from an isolated systems focus, to one in which the full product domain lifecycle is considered. Designers must look across current and planned products and address the impact of technology evolution and obsolescence on the system.

Development of a common asset base, and definition of the product line rules are

Product development pulls on the common asset base, adding new components and features, resulting in the intended product. The selection and tailoring of the product line assets, as well as incorporation of evolutionary changes, is a joint activity. Technical, organizational, as well as program management must be strongly committed to support the product line approach, if the effort is to be successful. Technical management is responsible for the core asset development, and all process and methodology activities, including configuration management. Organization management champions the product line, and ensures that proper resources are available to support evolution of the core assets. Program management defines the operational concepts and constraints for new products, and is responsible for the end product development.

After the product line area has been defined, it is essential to systematically manage planned variations across the product line, and exploit the commonalities, in order to realize the benefits of a product

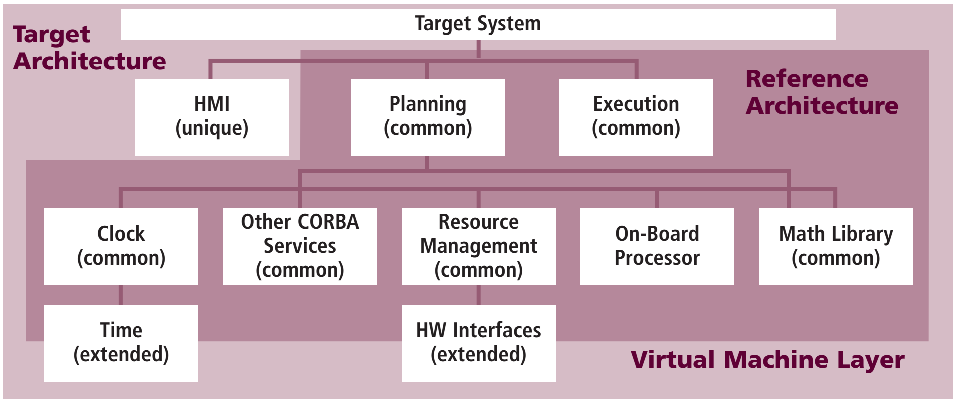


Figure 2. Example Architectural Layers for Domain Product Line Assets[2]*.*

line architecture. The product line must be able to evolve as the technology matures. A foundation, or reference architecture (Figure 2), that defines the system modularity and the basic guidelines and standards for commonalities, is fundamental to a product line strategy. The foundation architecture becomes a tool that relates a family of architectures, allowing an individual architecture to be created by selection from and modification of the framework components. It describes an information system in terms of a model, made up from a set of conceptual building blocks, and shows how the building blocks fit together. The foundation architecture defines the core operational environment, information interfaces, development environments, standards, organization, and processes.

Raytheon Product Line Architecture Successes

Raytheon has successfully applied a conceptual framework developed by the SEI for software product line practice that provides a comprehensive description of each practice area as it relates specifically to software product line operations and the common risks associated with each. This framework easily extends beyond the software boundary, and is being used as a guideline for successful product line development. More information on the SEI Product Line Systems Program can be found at http://www.sei.cmu.edu/programs/pls/pl_program.html.

Product line efforts across Raytheon are amortizing development investments through reuse of shared assets, including architecture, requirements, design, reusable components, schedules, budgets, test cases, documentation, training, process and people. Several examples of product line successes are given below and summarized in Figure 3. Additional information and contacts for these efforts are available on the Raytheon intranet at http://home.ray.com/pstn/technology_today.htm.

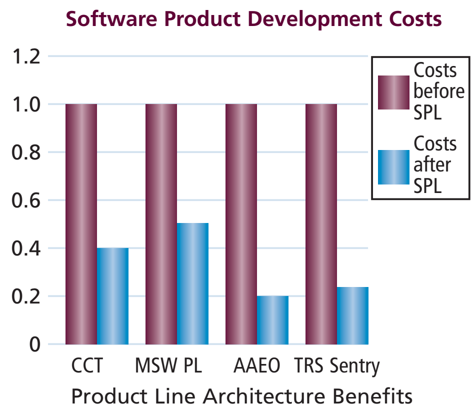


Figure 3. A product line focus has paid off in many Raytheon Company efforts.

Control Channel Toolkit (CCT)

Raytheon's Space Systems unit in Aurora, Colorado has developed a product line architecture for ground-based spacecraft command and control systems (also referred to as "control channels"). Satellite control channels provide ground processing support to spacecraft, allowing operations staff to monitor spacecraft functions, configure spacecraft service and payload systems, manage spacecraft orbits and attitudes, and perform mission planning. Called the Control Channel Toolkit (CCT), this software is used for ground based spacecraft command and control applications. The product line asset base consists of generalized requirements, domain specifications, a software architecture, a set of reusable software components, test procedures, a development environment definition, and a guide for reusing the architecture and components. Developed with support from the National Reconnaissance Office, the new product line's first system realized a 50-percent decrease in overall cost and schedule, and almost tenfold reduction in development defects and personnel. Some of the first systems to use the CCT reduced "as-built" SLOC counts by 76% of what was planned, and "as-built" design objects were 82% less than planned.

CCT has proved to be a "COTS-neutral" architecture, and provides straightforward mechanisms for integrating COTS.

The CCT as well as other Space Systems product line architectures comprise 79% of the software in the National Polar Orbiting Environmental Satellite System (NPOESS) system. This level of true software reuse was a significant factor in the Raytheon win of this important program.

Advanced Airborne Electro-Optical (AAEO) Product Line

The Advanced Program Development (APD) group Attack and Surveillance Systems of Space & Airborne Systems develops software and hardware for two main purposes, Air-to-Air superiority and Air-to-Ground strike. APD implemented a practical domain-based software reuse strategy for the Advanced Airborne Electro-Optics (AAEO) programs' product line. This strategy includes a good initial domain analysis, flexible systems/software architecture, and an organizational structure that ensures reuse would occur across the targeted programs.

The domain analysis relied on subject matter experts and program leadership to determine the top-level core applications for the product line, which included:

- An infrared search and track system that included a situational analysis and/or missile launch detection system,
- A targeting system interface,
- A navigation forward looking infra-red system, and
- An aided target recognition system.

The layered software architecture was designed to include a set of standard interfaces to services required by the core applications, including a simulation environment, test control and instrumentation system, and post analysis tools. The support structure includes those components needed by practically every core application. This support structure contributes significantly to the hardware isolation capabilities of the reuse strategy. It allows the core applications to run on different target platforms using a variety of sensors. A software architecture isolation layer encapsulates these generic services and buffers the applications from hardware changes.

The AAEO product line delivers software systems at 20% of the cost of those developed from scratch, has saved millions of dollars for the programs adopting it, and was key to capturing AAEO leadership in the Infra-Red Search and Track defense market.

Missile Software (MSW) Product Line

The Missile Software (MSW) Product Line in Tucson is still in development, but the initial system implementation has seen significant benefit. A pilot missile processing system implementation was built with the MSW toolset and middleware executing on target hardware. The system demonstrated a subset of IR detection processing planned for an upgrade to the Standard Missile program. Software productivity metrics showed a 50% increase in productivity for this program.

Command View™ Mission Planning Product Line

Thales-Raytheon Systems (TRS) in Fullerton, California has implemented their Command View™ product using a C4I software product line. Command View C4I systems provide command management automation for various military service branches and civilian emergency agencies. The product line has variants that support air, land, and joint level mission planning. The newest generation of this software product line, referred to as Command View II, is based on open-based component technology (Sun's Java 2 Enterprise Edition, J2EE), is fully Web-enable, and provides a modern N-tier architecture for easy adaptation to different mission planning jobs. This newest generation of the product line is being used as core air mission planning component of the NATO Air Command and Control System.

Sentry Air Defense / Command and Control System

Thales-Raytheon Systems also produces an air defense and command and control system product line called Sentry. Sentry systems provide situational awareness and a Single Integrated Air Picture (SIAP), threat evaluation tools and alerts, and will automatically make weapons assignments, provide interceptor guidance calculations to help vector fighters to their targets, and control Surface to Air Missile systems. Features for civil air traffic include flight plan display, correlation to the traffic in the SIAP, and correlation monitoring, to alert operators when traffic deviates from filed flight plans, or mission schedules.

These systems have been produced in Fullerton for 38 countries around the world. For the past 15 years, these systems have been built on 100% COTS hardware, and contain hundreds of COTS software products in addition to our Air Defense Product Library. Our last four programs have all seen software reuse of 75% to 95%. Costs have been slashed ten-fold. The software architecture was based upon an urgent need to reduce costs through software reuse, and developed under SEI Level 5 software processes.

Submarine Combat Control System (CCS) Mk2

Raytheon's Integrated Defense Systems in Portsmouth, Rhode Island, implements the Mk2 submarine combat control system. The Portsmouth facility has been involved in product line architectures associated with the CCS Mk2 lineage for approximately 25 years. Approximately one million lines of high-level code comprise the software base for the CCS Mk2. Facilitating this product line architecture is a common software real-time middleware based on open-standards and open-source.

The CCS has been installed on some submarines, and has been successfully employed in Operation Iraqi freedom. The CCS will soon be installed on all flights of submarines in the United States Navy. In addition, work will commence in the very near future for the Royal Australian Navy Collins Class submarine. Each of the systems installed on these disparate platforms are built from a common core set of applications that form the basis for the critical functions.

– Gillian Groves

Gillian Groves is Raytheon's Technology Area Director for Architecture and Systems Integration and chair of the Processing Systems Technology Network's Algorithms Technology Interest Group.

Guidelines and Lessons Learned

Product line guidelines from programs that have mature domain architectures:

- **Programmatics**
  - Have a 5-10 year program plan
  - Expect to invest in reuse – opportunistic reuse is only luck
  - Define an organizational structure to ensure reuse across the targeted programs
  - Involve your customer
- **Domain Analysis**
  - Necessary to describe and bound the functions of interest
  - Understand the desired various capabilities, as well as the requirements
  - Discover the reusable core of the domain
- **Develop a flexible product line architecture**
  - Hardware isolation: encapsulation of interfaces prevents propagation of change effects.
  - Design for evolution and customization
- **Culture**
  - Expect pushback. Engineers love to re-invent and re-design.
  - Reward design for reuse
  - Reward "not invented here, but we used it anyway!"
- **Keep good metrics — share the results!**

[1] Clements, Paul & Northrop, Linda. Software Product Lines: Practices and Patterns. Reading, MA: Addison Wesley, 2002.

[2] "CCT Program Concept of Operations", Raytheon Company internal document, March 20, 1998 (revision 0.4)

Processing Hardware Technologies

To affordably meet our customer needs, Raytheon combines our in-house technologies with third party and commercial, off-the-shelf (COTS) hardware to meet the broad range of size, weight, power, and environmental constraints imposed on our systems. Our in-house capabilities range from packaging technologies at the chip, board, and chassis level, to custom circuit designs. No matter what the challenge, Raytheon has the right technology to ensure our customers' requirements are met and our systems survive in a wide variety of challenging environmental, performance, security, and physical environments.

Processing Units and Boards

Raytheon's product requirements often demand custom or semicustom processing hardware. Experience has enabled us to use COTS or ruggedized COTS in many products, yet some customization is essential. High g shocks (>20g's) as found in projectiles require custom packaging. Small size and power constraints require innovative processing engines built with field programmable gate arrays (FPGAs) or custom application specific integrated circuits (ASICs) for hand held devices, missiles, and some avionics. Space applications also require custom architectures and ASICs to achieve low power (6-30 GOPS/watt) and radiation hardness.

Most common are custom processor units designed to meet unique system requirements for shape (e.g., round missile card), low weight, unique platform interfaces, or cooling methods. Custom modules are frequently intermixed with COTS modules, thus leveraging commercial investments. Unique system needs are derived using hardware-software co-design processes and modeled with performance evaluation simulations. Processing engines are benchmarked and shared across programs, leveraging Raytheon's breadth of work.

When custom modules or compute engines are required, we try to apply commercial standards and chip products. For example, Raytheon has developed many PowerPC based processor modules for embedded systems. Each has unique requirements for number of processors, memory, I/O ports, I/O protocols, or cooling requirements that preclude reuse of previous designs. Fibre channel is used on many of these to fulfill high speed I/O requirements. We work actively with industry to develop and enhance standards for use in our systems, such as when we recently chaired the Rapid I/O serial interface definition committee.

To fulfill warfighter needs for reliable, highly available systems, Raytheon products incorporate a test and maintenance architecture that employs patented methods for built in self test, failed module isolation, quick module replacement, and in some systems, fault tolerance for long life or battle damage mitigation.

Among Raytheon's most efficient processor designs are reconfigurable computers. FPGA versions were first used in field trials in 1996. These modules were eight times more efficient than available PowerPC processors for image based tracking. FPGA solutions are now used widely and are viable alternatives to custom ASICs. Signal processing throughputs of 100 GOPS per card are achievable, but we are going beyond that. Higher performance will be achieved using a deep submicron ASIC technology and a coarse grain reconfigurable processor developed on the DARPA sponsored MONARCH project, and is expected to achieve 1.2 TFLOPS per 6U board.

Advanced Packaging Technologies

While conventional integrated circuit (IC) packaging (1 die per package) offers off-the-shelf convenience, it does not offer the improvements in size, weight, power and operating speeds that can be achieved with Raytheon's packaging technologies.

Combining multiple die within a single package provides 4X-20X improvements in size and weight while significantly improving other performance parameters such as power (25% reduction) and speed (over 10X reduction in propagation delay times). Although more expensive than conventional packaging at the component level, advanced packaging technologies have been shown to achieve significant affordability improvements at the system level.

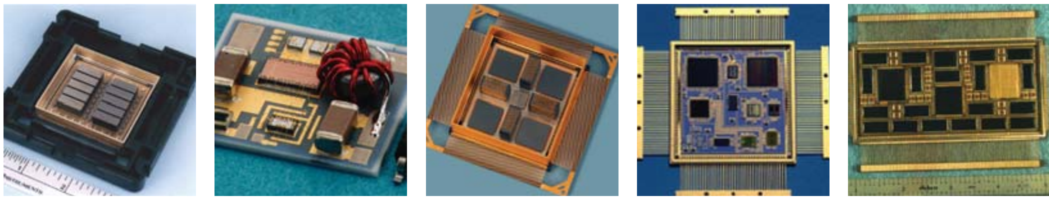
These improvements are achieved with advanced multi-chip module (MCM) assembly processes, including High Density Multi-Layer Interconnects (HDMI) as well as both 2D and 3D die attachment (die mounted vertically to reduce footprint) techniques. While many advanced technologies are available, Raytheon works to ensure that the minimum cost/risk technology is used to meet customer requirements. These advanced packaging technologies have been successfully applied to various processing modules, interface modules, memory modules and power supplies for space, airborne, and man portable applications.

Raytheon has combined its miniaturization technologies with advanced topologies and low profile magnetic designs to develop highly advanced power supplies. Power delivery densities of over 1000 W/in^3 and efficiencies of up to 95% are being delivered to customers today!

Examples of Raytheon's advanced packaging technologies are shown in Figure 1.

Custom and Semicustom IC Development

While the use of COTS ICs can make economic sense, there are times when a project requires features or functionality that cannot be met using existing devices. These situations require development of custom digital ICs — both ASICs and linear ICs. The benefits of such devices include small size,



NASA Deep-Space Memory Module | **High Efficiency Voltage Converter** | **AIM 9x Quad C40 Processor MCM** | **Cryptographic MCM** | **F22 Processor MCM**

Figure 1. Raytheon applies high density packaging to meet unique customer requirements.

power reduction, improved performance parameters (e.g. speed, throughput), integration of multiple standalone functions, radiation tolerance, or other customer-defined functionality. In addition, integration onto a single chip can enhance system security and protect intellectual property. Processing applications for which ASICs have been developed include signal processing, image processing and digital receivers.

Raytheon has demonstrated mastery of the ASIC design process and provided an extremely low risk development process. To further reduce the risk of procuring the completed designs, contractual agreements are in place with external foundries (including Honeywell, LSI Logic, TI and IBM) that ensure access to fabrication capabilities. Current ASIC designs have 0.09u feature sizes and complexities of 20M gates.

In the linear ASIC design arena there is an even wider range of services — where full turnkey delivery is offered. Internally developed linear designs are sent out for fabrication and packaging, but returned for advanced on-site testing. Raytheon currently tests and delivers over 100K linear ICs per year.

Raytheon also designs and tests radiation hardened ASICs used primarily for space missions. Designers mitigate radiation effects with a combination of architecture, cell library, and foundry selection. In house testers characterize the electrical and performance characteristics of the parts during and after radiation exposure.

Intellectual Property Protection

Growing in importance is the ability to "mask" integrated circuit designs so they cannot be reverse engineered. For some programs this is a critical requirement if the system is to be sold, or even deployed, internationally. To accomplish this goal, Raytheon has patented SecureIT™, a processing technique used in fabricated integrated circuits that prevents reverse engineering of the device. SecureIT™ is a set of specialized circuit layout methodologies that use standard complementary metal oxide semiconductor (CMOS) processing to make chips "functionally invincible" to reverse engineering.

SecureIT™ hides the functionality of circuits during the standard manufacturing process by:

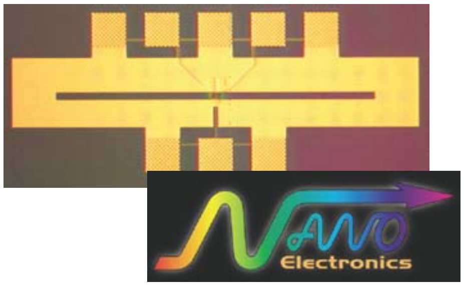
- Using BURIED transistor connections – microscopically enabled or disabled
- Making every CMOS transistor pair look identical, eliminating functional boundaries
- "Connecting" each transistor to all possible connections – resulting in hundreds of thousands of false connections

The result is that even for a small chip (10K gates), reverse engineering requires analysis of close to half a million hidden connections; and even an expert finds it extremely difficult — or not possible, for smaller CMOS sizes — to find and analyze each connection. Even at larger CMOS process sizes, a small chip would take 62.5 expert years of effort to reverse engineer.

Advanced Technologies

Raytheon is now entering the domain of Nanotechnology. Nanotechnology promises revolutionary advances in hardware and packaging technology that promises to make processing capability even more pervasive than it is today. We have partnered with the Massachusetts Institute of Technology (MIT), exploring the possibilities of weaving sensors into threads, and processors into fabric. Raytheon researchers are investigating the use of bio sensors and nano motors with the University of California at Los Angeles (UCLA) and nanotechnology self–assembly DNA linkage at the California State Polytechnic University in San Luis Obispo. We are also looking at magnetic paste, nano interconnects, nanostructured material, nano fluids and nano-based optical ceramics. To foster the engineering nanotechnology activity, Raytheon has established NEST, the Nano Engineering and Science TIG (Technology Interest Group)[1]. NEST has over 60 participating engineers at 16 Raytheon locations.

Electronic applications of nanotechnology are being developed based on quantum mechanical devices and circuits that push the limits on clock speed, power efficiency, and functional density. Quantum resonant tunneling devices are the fastest semiconductor switches, and can be used to build logic, analog-to-digital converters, and RF sensors that are many times faster that the fastest current transistor technology. Recently, Raytheon demonstrated a 100% direct digital nanoelectronic receiver operating at 660 GHz, breaking all records for speed and sensitivity in all-digital communications. This emerging technology will allow all types of RF systems to increase bandwidth, operating frequency, and software programmability.



Raytheon's 660GHz 100% direct digital receiver using a nanoelectronic A/D converter.

The Future

Raytheon innovation keeps moving advanced hardware technologies into products. High throughput, dense, reliable, easily programmable processing plays a major role in enabling system capabilities. Tomorrow's systems will provide incredible processing challenges:

- Months or years of battery powered processing operation with ultra low power, power aware computing devices.
- Teraops to Petaops of throughput in embedded flying systems.
- Networked processing systems supporting publish-and-subscribe real time access to raw or processed high resolution imagery.
- Tens of terabytes per second input data to dense signal processing hardware that performs all RF functions with a few common apertures.
- Immense, embeddable, self organizing data storage devices supporting multi mission fusion, correlation, and cognitive reasoning.

– Bill Kiczuk

[1] Nano Engineering & Science TIG, http://home.ray.com/pstn/nano.htm.

Software technologies and the associated development processes have grown exponentially over the last 50 years, since the genesis of the first computers and their accompanying software tools and languages. As predicted and articulated by many researchers and practitioners in the field, software has become the dominant component of the systems developed by Raytheon and other companies, for a myriad of industries and domains.[1] Our systems have evolved from single chip, embedded micro-code to the network-centric, distributed, real-time, embedded programs like DD(X), the US Navy's next century destroyer, that is expected to have on the order of tens of millions of lines of high-order language (HOL) code, running over hundreds of computing platforms. Systems of this order will require significant software research to accomplish the goal.

Software is increasingly the universal integrator for large-scale systems, which themselves are network-centric "systems of systems." Paradigms are needed that include careful engineering processes and systematic validation methods. Several questions need to be addressed to accomplish this mission. Such questions include the way in which software development will be accomplished. What can we expect the balance to be between formal and informal methods, engineering and artistry, evolution (reuse) and rebuild, correct-by-construction and correct-by-consensus? What role and effect will open-standards, open-source have in software development?[2] Additionally, given the global reach of many companies, and the advent of sophisticated collaborative development tools, what effect can be expected regarding the cost, schedule, quality, and other aspects of the systems development of the future?

Many of the systems recently fielded and currently under development are network-centric. These systems pose hard configuration and workload challenges including latency management, ability to handle partial failures, causal ordering, dynamic service partitioning and distributed deadlock avoidance.[2] Each of these issues require significant effort unto themselves to correctly design and develop solutions. An extensive effort is required to correctly address these issues simultaneously. Raytheon and others have successfully addressed these and many other issues via multiple approaches over the years. Many, many times, heroic efforts from the development and integration teams have been required to resolve these issues, very often via extensive trial-and-error and intensive hands-on activities for extended periods. Until recently, our systems have been stove-piped in nature, meaning that they have little interaction with other systems. Typically, these systems have brought along their own proprietary infrastructure middleware, distribution middleware, common services and domain-specific services as depicted in Figure 1. We have come to standardize on a set of computing platforms, network protocols, operating systems and the high order languages.

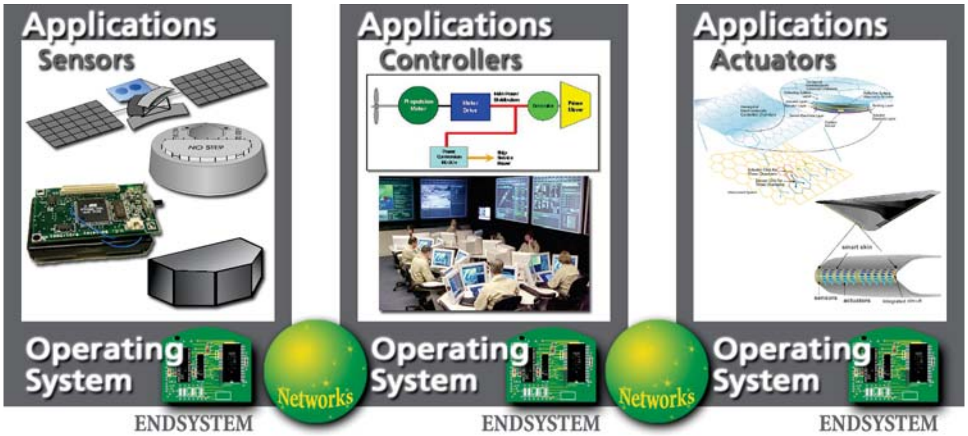


Figure 1. Stove-piped systems

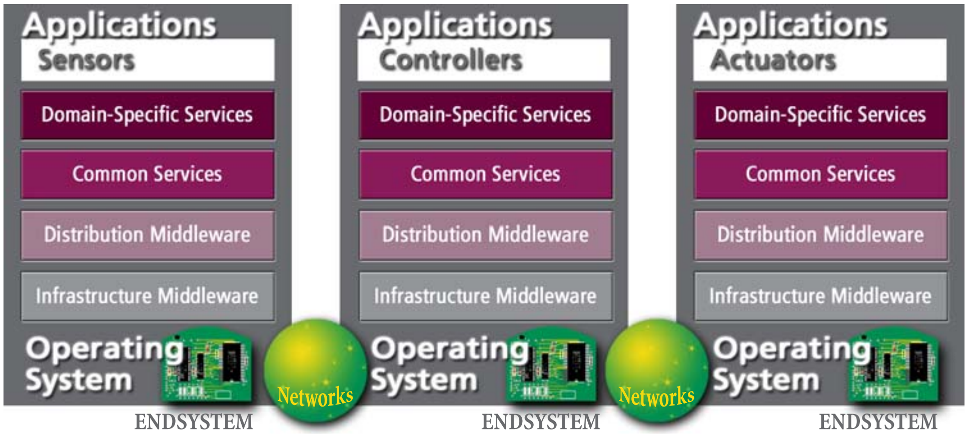


Figure 2 – Current trends of Systems Composition

The current trend, as depicted in Figure 2, is focusing on development of the systems' multitude of applications, which provides the highest value in the eyes of our customers. The other areas are increasingly becoming an off-the-shelf commodity from open-source groups as well as the traditional product/component vendors with which we are all familiar.

What is still needed is techniques, tools, technology and processes to address end-to-end quality of service, multi-level distributed resource management, adaptive middleware architectures, as well as system composition, i.e. building the software product. System composition in the future will be much different than today. It is anticipated that model-based system development will play a significant role in our future systems development, but significant, sustained research is needed to bring this concept to fruition. This area holds promise to reduce a product's time to market and development cost, and ultimately to increase our productivity. If research is successful in this area, the verification and validation effort can be substantially reduced and the latent defects that arise in the software will be dramatically reduced.

The Government, via the Defense Advanced Research Projects Agency (DARPA), the various Department of Defense (DoD) Research Laboratories (Office of Naval Research, Air Force Research Laboratory, Army Research Laboratory) and the National Science Foundation (NSF) has expended significant monetary resources, to the level of $300M, in advancing the state of the art in software technologies. DARPA, recognizing this need very early, assumed a leadership role across the spectrum of small grain and large grain systems for both design and systems development technologies as depicted in Figure 3.

Figure 3 – DARPA's Leadership Role in Software Technologies R&D

Specifically, DARPA is responsible for establishing the following programs, all focusing on advancing the state-of-the-art in a critical aspect of software technologies[3]:

- Software Enabled Control (SEC), which is developing advanced real-time control system algorithms and the software services and infrastructure necessary to implement them on distributed embedded processors in a robust and verifiable way,
- Model-Based Integration of Embedded Systems (MoBIES), which is developing technology to flexibly integrate the physics of the underlying domain with the embedded software design tools in order to custom-tailor the software process to the application,
- Program Composition for Embedded Systems (PCES), which is developing programming language & compiler technology that enables developers to safely & productively weave cross-cutting aspects such as throughput and fault tolerance with real-time embedded program functionality,
- Network Embedded Systems Technologies (NEST), which is developing robust coordination & synthesis services to support networked embedded systems of 100 to 1,000,000 nodes,

FELLOWS PROFILE

Reagan Branstetter

Reagan is a principal fellow on staff in the Missile Systems (MS) Electronics Center in Tucson and is the technical director of Advanced Processing Technology Developments for the Advanced Programs Product Line. He received a B.S. in Electrical Engineering from UT Austin in 1971, and joined the Texas Instruments Defense Systems Group that year. Reagan has been involved in development of high performance, real-time embedded processing systems and technology for advanced weapons systems for 24 years. He moved to the Raytheon Missile Systems organization in Tucson after the TI/Hughes/Raytheon merger. Reagan is also the IPT lead of the cross-functional Missile Advanced Processing Systems (MAPS) team chartered by MS Engineering to address multiple processing system development issues across all MS Product Lines. He formed the Multi-Program Computer team to exploit the synergy of a multiprogram shared development approach for implementation of a common processor architecture which is now implemented into multiple programs. He is also currently responsible for development of a gun hard Guidance Electronics Unit for the Mid-Range Munitions (MRM). MRM is the first program employing advanced autonomous target acquisition on imaging infrared seeker video in a 120mm projectile fired from a cannon.

FELLOWS PROFILE

Dr. Charles Hammons

Bud Hammons is an engineering fellow, software technologist, and software systems architect in Network Centric Systems where he supports System of Systems (SoS) architecture efforts centered on the Army's Objective Force-related programs. He brings valuable experience to this assignment, with over twenty years of experience in a variety of defense and commercial programs ranging from mission-critical embedded systems to enterprise distributed systems. He has served in leadership positions in a variety of leading edge software technology research and development programs, including the development of VHDL as part of the DARPA's VHSIC phase 2 program, and the development and application of Artificial Intelligence techniques to reduce pilot workload on DARPA's Pilot's Associate program. A critical emerging technology being applied to Raytheon's SoS architectures is Intelligent Agents. Dr. Hammons brings valuable experience to Raytheon in this area. He was one of industry's early researchers in agent-based systems design and development, having applied the technology on DARPA's Advanced Logistics Program in the mid 90's.

- Adaptive and Reflective Middleware Systems (ARMS), which is developing the new generation of middleware technologies for distributed real-time & embedded (DRE) combat systems to enable simultaneous control of multiple quality of service (QoS) properties and composable & customizable DoD common technology bases, and
- High Productivity Computing Systems (HPCS), which is developing new generations of high end programming environments, software tools, architectures, and hardware components in order to address the issues of low efficiency, scalability, software tools and environments, and growing physical constraints, and to provide economically viable high productivity computing systems for the national security and industrial user communities.

Advances in wireless networks, COTS hardware modeling, and VLSI synthesis technologies have already enabled lower-level aspects of network-centric systems. The investments of DARPA and other focused R&D efforts during the past decade are now yielding software technologies and tools that enable higher-level DRE middleware and model-based aspects of network-centric systems, making them tangible and affordable by generating, configuring, and controlling lower-level hardware, networks, and operating system mechanisms that affect mission-, system-, and application-centric QoS tradeoffs. The results of these R&D efforts are now yielding customizable—yet standards-compliant—technologies and tools that can:

- Automatically generate and optimize verifiably correct DRE middleware based on domain-specific languages and modeling tools,
- Assure flexible and QoS-enabled dynamically (re)configurable DRE middleware components,
- Manage distributed resources dynamically and dependably throughout multiple layers of DRE systems, and
- Formalize QoS-related design expertise by defining pattern languages that document and generate QoS-enabled middleware.

The future holds promise with the expected results from the aforementioned DARPA-sponsored software technologies R&D. Raytheon is working with DARPA on many of these programs in order to be among the first to understand and apply the resulting technologies.

Late breaking news! Raytheon has decided to become a founding member of the soon to be established government/industry Embedded Systems Consortium for Hybrid and Embedded Research (ESCHER). ESCHER will be focusing on long-term, pre-competitive research in embedded computing technology addressing the aforementioned software technology research areas. For additional information on ESCHER, contact either Lou DiPalma (Louis_P_DiPalma@raytheon.com) or Bill Kiczuk (Bill_Kiczuk@raytheon.com).

– Lou DiPalma

Lou DiPalma is the manager of the Integrated Warfare and Sensor Systems Software Department in the Software Engineering Center of Raytheon's Integrated Defense Systems and co-chair of the PSTN's and SWTN's Real-time Runtime Software Technology Interest Group.

1 Pressman, Roger. Software Engineering: A Practitioner's Approach. 5th edition, 2000. McGraw-Hill Inc.

2 NCO SDP Coordinating Group Report on New Visions in Software Design and Productivity, Vanderbilt University, Nashville, TN, Dec. 14-15, 2002

3 National Experimental Platform for Hybrid and Embedded Systems (NEPHEST) - Rationale for an Industry/Government Consortium, November, 2002

FELLOWS PROFILE

Robert E. Kelly Jr.

Bob is currently serving as the chief engineer for the subsurface Combat Control/Command and Control systems with Mk 2 ancestry in Portsmouth, RI. His diverse application background includes software intensive EW, radar and ATM systems. Current and previous programs have extensively leveraged COTS hardware and software. He has enjoyed a range of challenges from designing real-time I/O handlers to coordinating development of the operational concepts for the Canadian Automated Air Traffic System (CAATS), teaming with operations management personnel. The opportunity to work with a highly skilled team to successfully automate Canadian air traffic operations while achieving win-win operations decisions with the customer was a particularly rewarding and challenging assignment. Opportunities outside system development include participation on teams: evaluating and recommending automotive embedded operating systems; to formulating the roll-out of integrated product team development at the legacy Hughes Fullerton site. Current interests include middleware enhancement and standardization in real time scheduling and fault tolerance in distributed heterogeneous systems.

FELLOWS PROFILE

Mike Vahey

Mike is director of the National Digital Processor Product Center in El Segundo, CA. He is also chair of the Processing Systems Technology Network, which seeks to unite engineers working in various aspects of processing technology across Raytheon. He consults on some of the most challenging and important engineering programs in defense electronics. During his career, he has worked on everything from spacecraft systems to submarines. His current interests? Processor selection, processor design, system performance assessments and technology projections — to the 2010 time frame. His challenge: Driving high-performance processing technology that is 7 to 10 years ahead of commercially available processing. His current project is the High Performance Processing System (HPPS), a high density (1 Teraflop throughput, 10 watts power dissipation) processor intended for high throughput signal processing applications, particularly in space. Success with the HPPS will make Raytheon a clear leader in implementing advanced processing solutions on all kinds of platforms.

Voice of the Customer: *An Interview*

This interview has been abridged for publication. The full interview is available on the Raytheon Intranet at http://home.ray.com/pstn/technology_today/interview.html.

The following is a virtual interview with Dr. Douglas C. Schmidt, who is a Full Professor in the Electrical Engineering and Computer Science department at Vanderbilt University, and Dr. John S. Bay, a program manager in the Information Exploitation Office (IXO) at DARPA. Raytheon is working on several technology R&D programs managed by Dr. Schmidt and Dr. Bay, and they have consulted on several Raytheon programs. In addition, Dr. Bay was previously an Engineering Fellow at Raytheon. The questions were provided in writing and they responded separately in writing.

Q: What are the attributes of our future systems?

Bay: Future systems will be highly distributed, safety-critical, and subjected to the same stability and quality demands as other engineered systems, which must demonstrate their worthiness through watertight analytical criteria (notice how I avoided the term "proof"?).

Dr. John S. Bay has been with DARPA since April, 2001. He currently manages the Software-Enabled Control (SEC) and Model- Based Integration of Embedded Systems (MoBIES) programs within the IXO office. Prior to joining DARPA, he was an Engineering Fellow at Raytheon in Falls Church, Virginia, where he worked in robotics, command and control, and C3I advanced systems. Prior to that, he spent eleven years as a professor of electrical and computer engineering at Virginia Polytechnic Institute and State University in Blacksburg, Virginia. His academic research interests focused on control systems, robotics, machine learning, and embedded systems. Dr. Bay is a senior member of the IEEE, a former IEEE Computer Society Distinguished Visitor and a former associate technical editor of IEEE Control Systems Magazine. He is author of over sixty publications, including the textbook, "Fundamentals of Linear State Space Systems." He is a 1988 doctoral graduate of The Ohio State University, where his graduate studies included control systems, applied mathematics, statistics, and biomechanics.

Schmidt: Future DoD systems, such as total ship computing environments, next-generation coordinated unmanned air vehicle systems, and area/theater ballistic missile defense, will be network-centric distributed real-time and embedded (DRE) systems. These network-centric DRE systems include many interdependent levels, such as network/bus interconnects, many coordinated local and remote endsystems, and multiple layers of software. Some of the key attributes of future network-centric systems can be characterized as follows:

- Multiple quality of service (QoS) properties, such as predictable latency/jitter, throughput guarantees, scalability, dependability, and security, must be satisfied simultaneously and often in real-time;
- Different levels of service will occur under different system configurations, environmental conditions, and costs and must be handled judiciously by the system infrastructure and applications;
- The levels of service in one dimension must be coordinated with and/or traded off against the levels of service in other dimensions to achieve the intended application and overall mission results; and
- The need for autonomous and time-critical application behavior requires flexible system infrastructure components that can adapt robustly to dynamic changes in mission requirements and environmental conditions.

All these attributes are highly volatile and interwoven in network-centric systems, due to the dynamic interplay among the many interconnected parts.

Q: What is the next disruptive technology affecting these systems?

Bay: The disruptive technology to enable this development is predictive mathematical modeling of software systems. Such modeling will lead, for example, to model-based generative programming, producing executable code that is never touched by human hands, even—*especially*—in maintenance phases. A true "disruptive" technology is one that is adopted on its inherent virtues even if its payoff is not yet realized in application or commoditization. It provides a temporary step backward in order to facilitate greater gains later. Mathematical model-based development will cost the industry in retooling and retraining, but it will be to the software industry what the assembly line was to the automobile industry. In related ways, model-based process compliance will show similarly tangible returns, which may not be realized until the V&V stage. If a disciplined model-based development process is adhered to for the entire development lifecycle (there's another step backwards), V&V tools will close the development loop, doubling as requirements management tools, and the development cycle will become a living dynamic process with stability and correctness properties of its own.

Schmidt: I believe the evolution and increasing synergy between the following three software technologies will have the most profoundly disruptive impact on DoD system development and validation:

- **Quality of Service (QoS)-enabled component middleware.** Mastering the complexity of network-centric DoD systems requires a new generation of QoS-enabled component middleware technologies that can adapt dependably in response to dynamically changing conditions for the purpose of always utilizing the available computer and network resources to the highest degree possible in support of system needs. Network-centric systems include many interdependent levels, such as network/bus interconnects, local endsystems, and multiple layers of middleware. To satisfy highly application- and mission-specific QoS requirements, QoS-enabled component middleware must configure, monitor, analyze, report, and control the QoS of individual and aggregate resources used by multiple system/application components at multiple system levels. Examples of first-generation COTS QoS-enabled component middleware technologies include Real-time CORBA and Real-time Java. Second-generation QoS-enabled component middleware technologies include work on the Real-time CORBA Component Model (CCM) and Real-time/Fault-Tolerant CORBA, which are a focus of the DARPA Program Composition for Embedded Systems (PCES) program.

- Model-based software development. Decades of experience trying to control lifecycle costs of large-scale DoD systems make it clear that source code alone is inadequate for documenting and managing software design and maintenance processes. An important emerging trend therefore involves the integration of high-level, domain-specific modeling languages into the development process. These domain-specific abstractions are formal enough to be used directly for analysis of designs and for software generation. In addition, tools are emerging to facilitate developing and associating models post hoc with large quantities of software generated without them. Model-based software development technologies will help to create systems that utilize their own models to provide a wide range of new capabilities, such as self-monitoring, self-healing, self-adaptation, and self-optimization. Examples of first-generation model-based software development tools include SimuLink and StateFlow tools from MathWorks and Dome and Meta-H from Honeywell Technologies. Second-generation model-based software development technologies, such as Ptolemy from UC Berkeley, and the Generic Modeling Environment (GME) from the Institute for Software Intensive Systems (ISIS) at Vanderbilt University, are emerging from the DARPA MoBIES program and are starting to influence the Object Management Group's (OMG) Model Driven Architecture (MDA) standardization initiative.
- Multi-faceted programming. The increased fusion and deep integration of application domains with computing implies that essential characteristics of systems are strongly influenced—or simply determined —by the software. Consequently, software requirements become multi-faceted, i.e., computation and software architectures must satisfy many functional and physical requirements simultaneously. The goal of multi-faceted program composition is to separate design concerns by enabling (1) the simultaneous use and management of multiple design aspects, such as dependability, scalability, efficiency, security, and flexibility, and (2) the automated composition of systems that satisfy different objectives in different contexts. Multi-faceted composition efforts, such as aspect-oriented software development, are being integrated with paradigms working at different levels of abstraction, such as procedural and object-oriented languages, as well as declarative modeling languages. An example of a first-generation multi-faceted programming language is AspectJ, which is an aspect-oriented extension to Java created by researchers at Xerox PARC. Second-generation multi-faceted programming technologies, such as BBN Technology's Qoskets, are being developed in the DARPA PCES program.

Various incarnations of these middleware, modeling, and multi-faceted programming technologies are already being fielded in a variety of DoD systems, such as the Upgraded Early Warning Radar (UEWR) program, the Joint Tactical Terminal (JTT) and Joint Tactical Radio System (JTRS) programs, DD(X) and the Aegis Destroyer programs, the New Attack Submarine program, the Weapons Systems Open Architecture program, and the Unmanned Combat Air Vehicle (UCAV) program.

Q: What are the challenges facing software?

Bay: The biggest challenge to the industry is the image problem. The impression out there is that software development is completely unpredictable and unmanageable. This reputation is largely well-deserved. Nobody really has any idea what a system is going to do before it is executed. That is not to suggest that the answer is in the PR office; there are technological solutions available. For example, if we had more fail-soft systems and self-repairing systems, users would be less intimidated by complex software. This will require a revolution in the mathematical modeling of software systems that includes top-down (i.e., from a specification), and bottom-up (platform-dependent) representation.

Schmidt: The following are some of the key challenges that will require further major advances in software technology:

- Increased fusion of software into application domains. In many application domains, computing has become the key repository of complexity and the primary source of new functionality. For example, a substantial amount of the innovations in the defense industry come from embedded computing, particularly in the domains of precision weapons, signal and image processing, and command and control systems. The increased significance of computing means that unless unique characteristics of the application domain are reflected directly in the programming paradigms, application engineering considerations must be mapped manually onto general-purpose software engineering concepts and tools, which is tedious and error-prone. The difficulty of this manual mapping process motivates the need for carefully tailored capabilities, such as domain-specific languages, modeling tools, and QoS-enabled component middleware, mentioned earlier.
- Software has become the universal system integrator. One of the biggest impacts of the "IT explosion" in the last decade has been the emerging role of computing and software as the "universal system integrator." Complex systems have long been composed of interacting components. The new trend is that an increasing number of components and interactions in real-life systems are computational. For example, flight control

Dr. Douglas C. Schmidt's research focuses on patterns, optimization techniques, and empirical analyses of object-oriented frameworks that facilitate the development of distributed real-time and embedded (DRE) middleware running over high-speed networks and embedded system interconnects. He is an internationally recognized and widely cited expert on distributed object computing patterns, component middleware frameworks, and Real-time CORBA, and has published widely in top IEEE, ACM, IFIP, and USENIX technical journals, conferences, and books.

Dr. Schmidt has served as a Deputy Director and a Program Manager at DARPA, where he led the national R&D effort on DRE middleware. He has also served as the co-chair for the Software Design and Productivity (SDP) Coordinating Group of the U.S. government's multi-agency Information Technology Research and Development (IT R&D) Program, which formulated the multi-agency research agenda in software design. Dr. Schmidt received his Ph.D. in Information and Computer Science from the University of California, Irvine in 1994.

and avionics software systems keep airplanes flying. The consequences of these changes are twofold. On one hand, there is an ever-tighter fusion of computing and software with application domains. On the other hand, there is a strong divergence in software technology, since the field is becoming much richer with each new application direction.

- **Dynamically changing network-centric DRE systems.** As connectivity among computers and between computers and physical devices proliferates, DoD systems have become network-centric. Network-centric applications are inherently dynamic and must continuously change their topologies and adapt their functionality and interaction patterns in response to changes in their environment. Since much of this infrastructure can never be shut down entirely, it's essential to devise systems that can monitor and repair themselves and evolve continuously without disruption. Moreover, since these applications are inextricably connected to the physical environment, they must be designed to satisfy physical demands and limitations, such as dynamics, noise, power consumption, and physical size, in a timely manner.

Q: How would you recommend we overcome these challenges and deal with the fact that the complexity of software systems—particularly network-centric systems—is increasing faster than our ability to deal with it?

Bay: We need to come to grips with the fact that distributing a complex task among more and more programmers, or more and more components, is not the answer. We are already past the point of diminishing returns for that approach. Improved software engineering management tools won't fix this problem, nor will excessively fine-grained modeling approaches, which will eventually exacerbate overhead and interaction effects at integration time. The only viable long-term strategy involves some risk-taking in the embrace of the disruptive technologies discussed above. There is a fundamental problem that complexity brings, as well. Like mathematically chaotic systems that can be simultaneously deterministic and unpredictable, software systems are easily of sufficient complexity that human minds cannot possibly predict its behavior. Yet, we don't have sufficiently powerful tools to do this for us, either.

Schmidt: First, we need to recognize that there are different types of complexity in software systems. A substantial amount of the complexity of DoD software stems from so-called accidental complexity, which arise from limitations with tools and techniques we've used to develop software, including (1) the lack of type-safe, portable, and extensible native OS APIs, (2) the widespread use of functional decomposition and stepwise refinement, which makes it unnecessarily hard to maintain and extend large-scale DRE software, and (3) the continual rediscovery and reinvention of core DRE software concepts and capabilities, which keeps lifecycle costs unnecessarily high. DoD systems have also historically been developed via multiple technology bases, where each system brings its own networks, computers, displays, software, and people. Unfortunately, these proprietary "stove-pipe" architectures tightly couple many functional and QoS aspects of DRE systems, which greatly impedes their adaptability, assurability, and affordability.

Many of these accidental complexities can be resolved by a concerted focus on maturing COTS standards for DRE middleware and higher-level software development tools. Certain types of DoD systems, such as logistics and planning, are already being enhanced by COTS products and standards. Until recently, however, standards-based COTS solutions were not well-suited for mission-critical DRE systems due to either being (1) flexible and standard, but incapable of assuring stringent QoS demands or (2) partially QoS-enabled, but inflexible and non-standard. As this problem is resolved, DRE system integrators (and ultimately warfighters) will be able to take advantage of future advances in COTS technologies much more effectively.

Ironically, the accidental complexities described above are actually relatively easy to solve technically (though not always easy to solve politically and economically). An even more complicated type of problem stems from the so-called inherent complexities that arise from key domain challenges that complicate network-centric software development, including (1) selecting suitable communication mechanisms and designing protocols to use them effectively, (2) designing distributed services that utilize the available computing resources efficiently and reduce future maintenance costs, (3) using concurrency effectively to achieve predictable, reliable, high performance, and (4) arranging and configuring services to maximize system availability and flexibility. Effectively resolving these inherent complexities requires experience and a thorough understanding of many aspects of DRE systems and application domains. Ultimately, of course, this knowledge needs to be captured in higher-level software development tools and platforms that are tailored for the needs of DRE systems.

Q: How does the transformation to net-centric operations impact software technology, and vice-versa?

Bay: Net-Centrism is here. It is more a description of the state of the current consumer electronics and enterprise software industries than a vision of the future. Systems are largely built around assumptions of connectivity and there is little we cannot do at our desks if we have the money and motivation. I foresee a future where a single application can be assembled from readily available components. The users select the features a la carte—perhaps even from diverse vendors—and custom-configure an application that runs on a distributed platform. The embedded systems world has some catching-up to do because of problems with the link layer, physical layer, and security, but the logical/algorithmic principles are ready. From that perspective, I see net-centrism as currently a bigger driver of communications technologies than software technologies.

Q: How do you see us solving the software productivity bottleneck?

Bay: The same way the industrial revolution solved the mass production bottleneck: standardization of parts, design-for-assembly, and a focus on tools. Oh, and making the customer happy!

Schmidt: Developing quality software in a productive and cost-effective manner requires systematic reuse of successful software models, designs, and implementations that have already been developed and tested. Unlike opportunistic reuse (in which developers simply cut and paste code from existing programs to create new ones), systematic reuse is an intentional and concerted effort to create and apply multiuse software artifacts throughout an organization. In a well-honed systematic reuse process, each new project leverages time-proven designs and implementations, mostly just adding new code that is specific to a particular application, and only refactoring existing software architectures and designs when they become inadequate to cover the evolving business cases and variability in the supported domains. Systematic reuse is essential to increase software productivity and quality by breaking the costly cycle of rediscovering, reinventing, and revalidating common software artifacts.

Throughout most of the history of computing, the knowledge required to develop systematically reusable software has existed in programming folklore, the heads of experienced developers, or buried deep in the code. These locations are not ideal since the effort required to capture and evolve this knowledge is expensive, time-consuming, and error-prone. Many popular software methods and tools, such as UML and CASE tools, address certain aspects of these problems by documenting how a system is designed. However, they only support limited portions of software development and do not articulate why a system is designed in a particular way, which complicates subsequent software reuse and evolution.

It's been my experience that more effective ways to resolve the software productivity bottlenecks discussed above center on middleware, model-based software tools, patterns, and frameworks. Middleware and model-based software were discussed earlier. Patterns codify reusable design expertise that provides time-proven solutions to commonly occurring software problems that arise in particular contexts and domains. Frameworks provide both a reusable product-line architecture—guided by patterns—for a family of related applications and an integrated set of collaborating components that implement concrete realizations of the architecture.

Q: How will software be produced in the future?

Bay: Software will be developed through a series of certified transformations on a formal specification, through several analyzable stages of abstraction, to a fieldable system. Software engineers will focus on the transformations, not the code. Consider it analogous to the recording industry: nobody assembles the final recorded music in the studio note by note; instead they design the filters and process the components (tracks) in sequence before final assembly.

Schmidt: I see the following trends impacting the way in which software will be produced in the future:

- **Growing focus on integration rather than on programming.** There is an ongoing trend in the commercial and defense industries away from programming applications from scratch to integrating them by configuring and customizing reusable components and frameworks. While it is possible in theory to program applications from scratch, economic and organizational constraints–as well as increasingly complex requirements and competitive pressures–are making it infeasible to do so in practice. Many applications in the future will therefore be configured by integrating reusable commodity hardware and software components that are implemented by different suppliers together with the common middleware and model-based infrastructure needed to make it all work harmoniously.
- **The increased importance of open standards and open systems.** Shrinking profit margins and increasing shareholder pressure to cut costs are making it harder for companies to invest in long-term research that does not yield short-term pay offs. As a result, many companies can no longer afford the luxury of internal organizations that produce completely custom hardware and software components with proprietary QoS support. To fill this void, therefore, standards-based hardware and software researched and developed by third parties–and glued together by common middleware–is becoming increasingly strategic to many industries. This trend also requires companies to transition away from proprietary architectures to more open systems in order to reap the benefits of externally developed components, while still maintaining an ability to compete with domain-specific solutions that can be differentiated and customized. The refactoring of certain layers of domain-independent middleware and operating systems into open-source releases based on open standards is spurring the adoption of common software infrastructure in many industries, including the DoD. It is also emphasizing the role of domain knowledge in selecting, organizing, and optimizing appropriate software components for requirements in particular application domains.

Q: How do you see us successfully conquering the Verification & Validation Challenge?

Bay: By abandoning our stubborn insistence that exhaustively poring through code line by line is the only acceptable way it will ever get done. With complex large scale systems, it is not possible to get an accurate functional picture with microscopic perspectives of the system. If we build trusted tools, we can achieve correctness by construction, and much of the V&V problem will solve itself. A major source of errors, incorrect specifications, will remain, but researchers are working on that, too.

Q: From a software perspective, what keeps you up at night?

Schmidt: I'm now losing sleep over the following strategic concerns:

- **Failure to motivate the need for fundamental software R&D investment.** Software has never been more strategic to DoD success. However, the research community has been ineffective at sparking interest in software-related R&D from DoD funding agencies and services in recent years. It's clear from the success of the Internet that truly revolutionary information technology breakthroughs take decades to mature. We don't seem to be doing very well as a community, however, at articulating the need for fundamental software R&D investments. With much of the US IT industry in shambles, it's becoming increasingly clear that the commercial industry alone cannot solve all the long-term software R&D challenges. Yet we're not being very successful at motivating and shaping the future needs of our potential consumers and sponsors.
- **Potential complexity cap for next-generation complex systems.** During the .com boom in the late 1990s, there was a steady flow of faculty, staff, and grad students out of the traditional research centers, such as universities and

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Excellence in Technology

2002 Distinguished Level Awards Ceremony

Imagination, Creativity, Knowledge, and Passion = Technology Excellence.

On April 15, 2003, the Smithsonian National Air and Space Museum (NASM) in Washington, DC was the venue for the 2002 Distinguished Level Excellence in Technology awards celebration. Eight individuals and 24 teams from the Raytheon businesses were presented with Raytheon's highest technical honor.

Dan Burnham, Raytheon chairman and CEO, and Bill Swanson, Raytheon president, hosted the evening. After a reception in the Space Hall, the evening's emcee, Pat Coulter, vice president of communications, Defense Systems, called everyone to order for the start of the ceremony in the Milestones of Flight Gallery.

General Jack Dailey (Ret. USMC), Director of the NASM, opened the evening stating "Let me welcome you and tell you what a pleasure and an honor it is to have you in this… Milestones Gallery. This is the type of event we should have at this museum. Recognition of leaders and those who have excelled in the aerospace industry."

"Tonight we celebrate your invention and your innovation. One day the technologies that you are developing may very well sit in these buildings. As you walk the halls tonight, take a look at the many programs and products that Raytheon has touched here in these galleries. Our leadership in intelligence, surveillance, reconnaissance, missile defense, precision strike, homeland security are just a few of the examples of how our technology is being put to the test each and every day and we owe it to you", exclaimed award sponsor Greg Shelton, vice president of engineering, technology, manufacturing and quality. Greg surprised the attendees with an inspiring technology video that provided a brief synopsis of Raytheon's technology history and clips from the four strategic technology areas.

"Technology is the heart and soul of Raytheon and you are the standard bearers of technical excellence. Please be leaders and show others who are just coming up the path to excellence" stated Bill Swanson. Swanson humored the audience when he introduced Dan Burnham and presented him with an "honorary engineering award". The award consisted of a pocket protector, slide rule, ESD straps and safety glasses. Dan readily accepted his award and placed the pocket protector, fully loaded with mechanical pencils, colored pens and a metal scale in his pocket.

Dan Burnham gave an inspiring keynote address. "This is the best part of my job — recognizing excellence at Raytheon. Congratulations to all of the recipients of this prestigious award. Welcome to the spouses and guests here tonight — and welcome to the members of our Leadership Team. It's wonderful to have you all" stated Dan as he opened his address

"Tonight, we're celebrating technology, and we're recognizing your creativity and passion — the way you put science and math to work. You enjoy challenges. You have a fierce integrity. You are skeptical — but you are not cynical. And here, in this gallery, you are in good company — with the historic accomplishments of those who came before you."

"Thank you for all that you have done and all that you are doing — for our company, our men and women in uniform, and our quality of life. You — the achievers of excellence in technology — have the opportunity to continue to use your intelligence, curiosity, and passion to create new milestones, to inspire future generations, to fill this gallery of human progress with more wonderful achievements."

As Goddard said, "It is difficult to say what is impossible, for the dream of yesterday is the hope of today — and the reality of tomorrow." Thank you for transforming our dreams and hopes into reality. Congratulations again.", remarked Burnham as he closed his address.

Citations and the presentation of the awards followed the keynote address. After the presentation of the awards, guests were allowed private access to the museum galleries as well as an IMAX theatre show.

Raytheon is a technology company. The people who were honored are what make this company great — their hard work, dedication and pursuit of excellence are what this company is all about. Raytheon is a great company and keeps getting better. Seek out the 2002 Excellence in Technology winners, congratulate them and get to know them.

Take a moment to view the highlights of the event, Dan's keynote address, personal remarks from the awardees, the Raytheon technology video and the video/photo galleries on the Engineering & Technology Web site at **http://home.ray.com/rayeng/people/awards2002/awards2002.html**

2002 Excellence in Technology Distinguished Award Winners

<u>Homeland Security</u>
Redwolf XG Product Development Team
Carolyn Andrukonis, Dan Horvath, Dennis Koranek, Art Stefanelli, Barbara Wordsworth

<u>HRL</u>
HRL Advanced Receiver Team
Albert E. Cosand, Robert A. Ferreira, Joseph F. Jensen

<u>Integrated Defense Systems</u>
Career Achievement in the Development of Infrared Optical Materials
Charles B. Willingham
Leadership in Radar Discrimination Technology
Denis J. Donohue, Brian J. Harkins, Arthur B. Johnson, James E. King, Donald J. Power
Metamorphic HEMT Development Team (formerly RCE)
Phil Balas, Steve Lardizabal, Peter Lyman, Phil Marsh, Colin Whelan
Ships Self Defense MK 2 Distributed Open Architecture Integration Team
Kathy Emery, Mark Hodge, Ron Klein, Daniel Neumann, John Peterson
SPY-3 Radar Systems/Software Technical Leadership
James P. Barry, Daniel P. Harty, Robert Kingan, John E. Page, Kent C. Varnum

<u>Intelligence and Information Systems</u>
Commercial Standards/Technology Innovation in Ground Station Systems Team
Bruce Bohannan, Frank DeLuca, Lloyde Richmond, Terry Stocking
Technical Leadership in Information Security
Kevin Cariker
MCS Scheduling Algorithm Analysis Team
Gregory G. Melvin, Michael R. Radebaugh, Noralie J. Sarver, Thomas M. Tanner, Daniel J. Weeks
Mitigation of External & Cosite Interference for ACN
Howard E. Nichols

<u>Missile Systems</u>
Advanced Avalanche Photo-Diode Array for Laser Radar Demonstration Team
Steven L. Bailey, Michael D. Jack, Pat Trotta
Advanced Manufacturing Tooling Development Team
Brian Alfing, Walter Wrigglesworth
Advanced Tactical Targeting Technology Team
Steven A. Fioccoprile, Douglas C. Lytle, Thomas F. Markarian, Daniel R. Pinda, David J. Smith
Career Achievement in Electro-Optical Tactical Space Advancement
Kent Pflibsen
Imaging Spectroscopy Team
Dennis Garrood, Garrett L. Hall, Harvey C. Schau, Ross E. Soulon

<u>Network Centric Systems</u>
Advanced Multispectral Focal Plane Array Development
Paul M. Goetz, Elizabeth Patten, Le T. Pham, Gregory Pierce, Edward P. Smith
Amorphous Silicon Detector Team (formerly RCE)
Roland Gooch, William McCardel, Thomas Schimert, Athenasios Syllaios, John Tregilgas
Enterprise Scalable Intrusion Detection System Development Team
Jon-Michael C. Brook, Randall S. Brooks, Matthew C. Rixon, Troy Rockwood (HRL)0
EPLRS Micro-Light Development
James S. Tsusaki
Excellence in Cooperative Engagement Capability Development & Deployment
Dennis J. King
RSTA MEP Development Team
John Bosch, Douglas Darlington, Randy Gann, Dwayne Morrison, David Pelkowski
Uncooled TWS System Simulation & Performance Characterization Team
Jim Andrew, William Bowser, Todd Sessler, R. Mike Stokes, Ross Williams

<u>Raytheon Aircraft Company</u>
T-6A Weapon/Store Separation Trajectory Team
Frank Coot, Randy Fisher, Stephen W. Koontz, Stan Lemke, Pat Renze

<u>Raytheon Systems Limited</u>
Motor Drive Development Team
Jim Bissett, Karen Clark, David Gordon, Alasdair MacIver, Ian Young

<u>Raytheon Technical Services</u>
Discovery of the Reversal of the Earth's Gravity Field Rebound Effect
Christopher M. Cox
Space Station Training Facility Robotics Development
Kim L. Gastler, Jerry B. Pace, Luis E. Pena, Jose A. Tovias, Marcus J. Turner

<u>Space and Airborne Systems</u>
ALR-69U Radar Warning Development Team
Lynne Barber, Dayle Good, Roderick A. Newstrom, Richard A. Poster, Richard Tate
APG-79 AESA Receiver/Exciter Team
Ron Chan, Steve Hsu, David Julifs, Howard Nussbaum, William Posey
Career Achievement for Excellence in Optical Design & Engineering
Lacy Cook
KIRIN Technology Development Team
Doug Bostrom, Brian Considine, Jonathan Gordon, Robyn Robbins, Adam Von
Uncooled FLIR Electronics Team
John Steve Anderson, Frank Cheung, Richard Chin, Hector Gonzalez, Dung-Steve Ton

"Be a Lifelong Learner" What does it mean to you and Raytheon?

Changes in technology drive the need for a commitment to continuous learning. ***To continue working with a leading edge technologies, lifelong learning must be a part of your ongoing career activities. Some people are fortunate enough to be a part of that leading edge of technology, while others experience technology life cycles that tend to be shorter and shorter. For example, have you kept up with the latest changes to desktop operating systems: Windows 3.1, 3.11, 95, 98, NT, 2000, and now XP?*** **Technology is one driving force that requires you to keep current with the latest changes.**

How Raytheon Supports Lifelong Learners

Raytheon provides a multitude of learning opportunities for engineers that promote career growth and professional development, while improving design and development through the use of standard processes and tools. Learning is especially relevant to those opportunities that build current job role competencies and/or promote career development.

We must continuously improve engineering talent to help individuals excel and to meet business priorities. It is essential that our engineering community have the ability to drive competitive advantage. This requires a commitment to lifelong learning.

This is also an important step toward making Raytheon the "Employer of Choice" where the best people aspire to work. Raytheon's extensive learning opportunities have resulted from a strong partnership between site training teams, the Raytheon Learning Institutes (RLI), the engineering enterprise discipline teams, and the business units. This partnership is focused on the need to keep our technical population proficient. Career-long learning is a critical attribute of an organization's competitiveness.

What's Involved in Supporting Lifelong Learning

Learning can take many forms. Some people learn best in a classroom situation. Others learn from presentations that can be replayed as needed. While others prefer interactive computer based training applications to learn. Learning can occur in many places — in the classroom, on the job, in the office reading, or while attending conferences.

RLI's Engineering Institute collaborates with the engineering councils on curricula in the major engineering disciplines to create world-class training for the continuing development of our engineering talent. Engineers need to expand their knowledge in their technical discipline as well as related domain areas. For example, a software developer should understand object-oriented technology, as well as radar processing applications. You can also share your expertise as a subject matter expert in situations that help others to learn.

The purpose of any training program is to develop the skills and knowledge of the people, to prepare them for future business needs, and to enable their personal career development. We use structured (e.g. classroom training, computer based training, facilitated video, and guided self study) and informal (e.g. on-the-job training, brown bag lunch seminars, mentoring, reading books, and technical journals) vehicles based on individuals' roles to impart those skills more effectively and efficiently.

We accomplish the skill development of our people by identifying the training requirements for the organization, the projects, and the employees. We then develop or procure training to address the identified needs. In addition, we make a concerted effort to identify and teach best practices throughout the enterprise. Our culture and strength is embracing best practices, and deploying them just-in-time to meet our customer commitments.

A training program has four key inputs, which are directly linked to one another. They are the Individual Development Plan (IDP), Organizational training plan, Functional training plan, and the Project training plan.

The employee and team lead or supervisor initially develops the individual development Plan. The plan should be reviewed and updated throughout the year or as appropriate (e.g. a significant job assignment change). The result of this process can be stored in Raytheon's Learning Management System (LMS). The LMS also tracks an employee's training history. All US based employees have access to the LMS at http://pregistrar.rsc.raytheon.com.

Organizational training plans include business specific needs. It is closely aligned with the Functional training plan. This is created by each engineering discipline and reflects the competencies required for the various positions within the discipline and the training that is currently available to develop those skills.

The Project training plan provides a project with the opportunity to specify training unique to a project.

How RLI determines what training to offer

Business learning needs often dictate the amount of support an organization can provide for training. There may be budgetary or schedule constraints imposed on learning options made available to engineers. Competency models reflect the skills needed for a particular position. Individuals should complete a skills gap assessment to determine their gaps, and develop a plan for improvement.

Individual development plans, completed by each employee after discussion with his or her supervisor, will be used to determine:

- What classes will be scheduled and how often
- What new classes are needed
- Inputs to the training budgeting process

Competency can be defined as the quality of being adequately or well qualified. This is useful in the context of determining if a person has qualified for a particular job assignment. This pre-supposes the existence of a competency model. Several engineering areas within Raytheon are working on their competency models. This includes software, systems engineering, mechanical, Analog-RF-Microwave, and others. Check the "Guidelines/References" section of IPDS to find some Competency models at http://home.ray.com/ipds.

Your Role in Lifelong Learning

Learning occurs in many ways and places. You need to find the best technique for you. It may be structured learning events or informal eLearning opportunities. You need to determine the gap between your current skills and skills listed on the competency model for your discipline. Once determined, meet with your supervisor to chart a plan to cover those gaps. Another role may be to read, learn, and share your knowledge with your co-workers.

- Victor Wright

Promoting One Company Solutions. Driving value across the Enterprise.

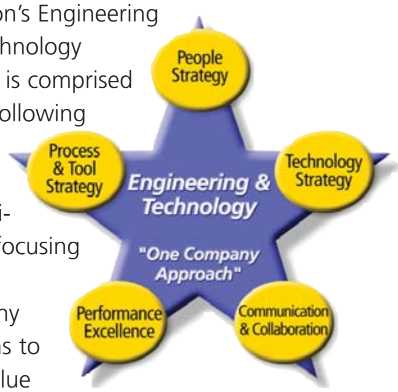
In 1998, the engineering and technology leaders decided to form a cross-segment (SES, DSS, C3, IS, AIS of the former Raytheon Systems Company (RSC)) council and called themselves the Engineering & Technology Council (E&TC). Their purpose was to unite our company's engineering communities, bringing the "best of the best" together, and promoting a One Company philosophy. The E&TC continues on, chaired by Greg Shelton, vice president of engineering, technology, manufacturing and quality for Raytheon Company, and is comprised of the engineering vice presidents from each business along with the corporate engineering and technology staff. The E&TC is a business centric engineering and technology leadership council that communicates, collaborates, and shares best practices and lessons learned across the businesses.

The mission of the E&TC is as follows:

1. Leverage our technology with cross-business opportunities and solutions to maintain our competitive advantage through synergistic product development and technical reuse.
2. Coordinate shared initiatives such as IPDS, CMMI, and Raytheon Six Sigma enabling cross-business collaboration on programs efficiently, moving toward "Design Anywhere, Build Anywhere", improved productivity and reliable, consistent program execution.
3. Foster open and direct communications by sharing information, accelerating the cycles of learning, leveraging lessons learned, our expertise, and our diversity across the company.
4. Promote a culture of continuous learning and professional development for our engineers and technologists.
5. Demonstrate engineering excellence by measuring our performance, using this information to make fact-based decisions for continuous improvement in everything we do.
6. Provide guidance and direction to the discipline engineering and technology councils linking the Engineering community throughout all of Raytheon.

To leverage our size and diversity across the company, the E&TC established the Raytheon Common Process Program (RECP) to enable and facilitate business common initiatives in the area of engineering and technology. Some these common initiatives include: IPDS, CMMI, Collaborative Product Development, Technology Networks, engineering collaboration and engineering communication.

Raytheon's Engineering and Technology Council is comprised of the following leaders each of the businesses focusing on One Company solutions to drive value across the enterprise.



Greg Shelton – Corporate Engineering, Technology, Manufacturing and Quality

Greg Shelton is vice president of engineering, technology, manufacturing and quality for Raytheon Company. In this role, Shelton is responsible for developing and implementing enterprise engineering and program management processes and tools, and integrating technology strategies, roadmaps and competitive assessments. He also oversees program performance and execution, as well as setting company-wide quality policies.

Shelton has more than 30 years experience within the defense industry and has held a wide range of challenging positions in engineering, program management and engineering leadership.

Shelton is the vice-chairman of the President's Council for Olin College of Engineering. He is on the engineering advisory boards for the University of Arizona and Tuskegee University. He is a member of the MIT executive operating committee for LFM-SDM and the Engineering in Mass Collaborative executive committee. Shelton also serves on the HRL Research Laboratories board of directors.

A native of California, Shelton holds a bachelor's degree in electrical engineering from California Polytechnic University and a master's in engineering and management from the University of California Los Angeles. In 2002, he was elected associate fellow for the American Institute of Aeronautics and Astronautics.

Peter Pao – Corporate Engineering, Technology, Manufacturing and Quality

Dr. Peter S. Pao, vice president of corporate technology is responsible for creating Raytheon's technology vision and coordinating and overseeing the development and execution of technology strategies for all Raytheon Businesses. Technology is the foundation of Raytheon. It differentiates us from our competitors. Peter works with all Raytheon businesses to create a technology strategy that balances long-term growth requirements with near term business needs. He also works to optimize Raytheon's technology investment by leveraging technology synergy among Raytheon businesses and improve Raytheon's effectiveness by aligning with strategic partners.

Prior to assuming his current vice president (VP) role, Peter has held a number of key positions over the years, including VP of engineering and technology for Electronic Systems, vice president and deputy general manager for Air Combat and Strike Systems, director of the F-15 Program and VP of the Sensors and Communications Systems Segment at Hughes Aircraft Company.

Peter holds a Bachelor of Science degree in mathematics from Fu-Jen University in Taiwan and a Ph.D. in mathematics from the University of Michigan. He is also a graduate of the University of Southern California Executive Management Program.

Karen Steinfeld – Homeland Security

Karen Steinfeld, director of engineering for Homeland Security (RHS), is responsible for engineering leadership, technology assessment, and system architecture definition. RHS seeks to be a market leader for homeland security solutions and a contributor to the safety of America and its people by targeting the areas of Information and Intelligence Analysis, Physical Security, and Emergency Response. RHS, a virtual organization, truly embraces One Company behavior by working with a variety of Raytheon's businesses to be successful at capturing and executing programs.

Karen has held a variety of engineering and engineering leadership positions within Raytheon over the past 19 years, including integrated product team lead within the Electronic Warfare and Signal Processing business, software manager for the Telecommunication Surveillance Products group, and most recently, engineering manager for Advanced, Emerging, and Telephony Systems within Raytheon's Strategic Systems business. In 1997, Karen played a significant role in Garland, Texas' first successful SEI CMM Level 3 assessment. Karen also served as the Mid-Atlantic engineering diversity champion for two years and in that role increased Mid-Atlantic engineering's participation in diversity-related events and championed the creation of the Mid-Atlantic Black Professional Organization.

Karen earned a Bachelor of Science degree in Information and Computer Science from the Georgia Institute of Technology in Atlanta, Georgia.

Mark Russell – Integrated Defense Systems

Mark Russell, vice president of engineering for Integrated Defense Systems (IDS), is responsible all engineering activities including capture and management of technology programs, continuous process and tool improvements and product development. Over the past 20 years, Mark has served as director of Surface Radar Engineering and earlier as director of Radar Design and Electronics Center for Raytheon's Electronic Systems business.

Mark holds patents in microwave and millimeter wave components, high-range resolution radar applications and missile seekers. He has also published papers in active electronically steered arrays and radar systems, missiles, photonic technology and communication systems to name a few.

Front row: Bob Kern (SAS), Dave Riemer (RAC), Greg Shelton (Corporate Engineering & Technology), Karen Steinfeld (Homeland Security), John Grimm (IIS), Paul Diamond (MS). Back row: John Gatti (RTSC), Alan McCormick (RSL), Jerry Powlen (NCS), Mark Russell (IDS), Peter Pao (Corporate Technology)

Mark holds a Bachelor of Science degree in electrical engineering and a Master of Science degree in electrical engineering from the University of Massachusetts.

John Grimm - Intelligence and Information Systems

John Grimm, vice president of engineering for Intelligence and Information Systems (IIS), is responsible for more than 4000 employees located throughout Texas, Colorado, Virginia, Maryland, Pennsylvania and Nebraska. John's vision for engineering states *"We Create and Deliver Value to Our Customers"*. This vision is realized through a commitment to clear and consistent communications with peers, partners and customers, by gaining a competitive advantage through the disciplined application of IPDS, CMMI and Raytheon Six Sigma, and by accepting accountability for business growth and program execution.

Prior to assuming his current VP role, John has held a number of key positions including VP of engineering for Imagery and Geospatial Systems (IGS) and VP of engineering for Intelligence, Information and Aircraft Integration Systems. He has more than 32 years experience in engineering management and systems engineering, including applications to radar systems, signal processing, digital processing subsystems, computer architecture and software development.

John holds a Bachelor of Science degree in electrical engineering from Louisiana Tech University and a Master of Science degree in electrical engineering from Louisiana State University.

Paul Diamond – Missile Systems

Paul Diamond, vice president of engineering for Missile Systems (MS), is responsible for approximately 5000 employees who perform engineering and technology development of missiles, directed energy, guided bombs and projectiles. Paul has 35 years of engineering and management experience. Prior to assuming his role as VP in 2001, Paul has held several key positions in Radar, Systems Engineering and Product Line Management within Raytheon and Hughes Aircraft.

MS Engineering's main focus for 2003 is to shorten the design cycle, improve manufacturing yields and reduce product cost. Key initiatives include a campaign to achieve CMMI Level 3, improving Design for Six Sigma and developing a robust design for the unit cost process.

Paul received a Bachelors degree in Electrical Engineering from City College of New York and a Master of Science in Electrical Engineering from Northeastern University.

Jerry Powlen – Network Centric Systems

Jerry Powlen, vice president of engineering for Network Centric Systems (NCS) is responsible for approximately 6,000 employees located primarily in California, Texas, Indiana, Florida, and Massachusetts. In 2003, developing an integrated, comprehensive technology roadmap to support the NCS business strategy is an Engineering priority. Leveraging skills and collective capabilities across this geographically diverse business requires a disciplined collaborative process and new tools to support it. A focus on business execution, another priority, helps ensure proper deployment and execution of previously developed engineering processes.

Prior to assuming his role as VP in October 2002, Jerry was Director of Light Forces product line within the Tactical Systems Business. He has held a variety of positions over the past 22 years in Quality Assurance (QA), Cost Estimating, Proposal Management, Finance, Financial Planning and Business Operations, both at Raytheon and Texas Instruments.

Jerry is a graduate of Syracuse University, where he received a Bachelor of Science degree in Operations Research/Statistics. He also holds a Master of Science in Management from the University of Texas at Dallas with an Accounting/Finance focus.

David Riemer – Raytheon Aircraft Company

David Riemer assumed the role of vice president of Product Development and Engineering for Raytheon Aircraft in November 2002. In this position, he will focus on directing and managing new product development programs for future growth, including Horizon, and all major product upgrades.

Prior to his current role, David has held a number of key positions throughout his 23-year career with Raytheon Aircraft and Beech Aircraft, including VP of Government Business, VP of Trainer Systems Division and VP of JPATS program. He also manages Government Marketing, Special Mission Aircraft, Beechjet/T-1A and U-125A programs.

David holds a Bachelor of Science degree in Computer Science, with minors in Mechanical Engineering and Finance, from the University of Utah and a Master of Science degree in Mechanical Engineering from the University of Utah.

Alan McCormick – Raytheon Systems Limited

Alan McCormick assumed the role of director of engineering and technology at Raytheon Systems Limited (RSL) in February 2002. Prior to his current role, Alan was the director of engineering for AMS Radar Systems Division. He also spent nine years on the Isle of Wight with Siemens Plessey Systems, holding a variety of positions.

In 2003, Alan's goal for the Engineering Process Group is to become a world-class engineering organization by year-end with a reputation for being the best and whose excellence is recognized across Raytheon and the industry.

Alan holds a Master of Science and a Ph.D. in electrical and electronic engineering from Heriot Watt University in Edinburgh, England.

John Gatti – Raytheon Technical Services Company

John Gatti was appointed vice president of engineering for Raytheon Technical Services Company (RTSC) in April 2003. In this role, John will help implement RTSC's business strategy by focusing engineering and technology resources to provide innovative solutions for their customers and to improve the way they do business. John is also an active member on several councils and teams in Engineering's cross-business collaboration efforts.

Prior to this appointment, John was the director of engineering for Integrated Product Development at Corporate Engineering and Technology. He managed the Raytheon Engineering Common Program (RECP), which is responsible for Raytheon engineering and technology projects, such as IPDS and CMMI. He has worked in a variety of program and functional management positions over his tenure with Raytheon.

John earned a Bachelor of Science degree in Mechanical Engineering from Norwich University's Military College of Vermont. He is currently completing his Master of Science at Massachusetts Institute of Technology in the Systems Design and Management Fellow program.

Bob Kern – Space and Airborne Systems

Bob Kern, vice president of engineering for Space and Airborne Systems (SAS), is responsible for more than 5600 engineers located in El Segundo and Goleta, Calif., Dallas, Texas, and Forest, Miss. SAS, which generates approximately $3 billion in revenue, is comprised of advanced technology solutions for Intelligence, Surveillance, and Reconnaissance (ISR), Missile Defense, and Precision Strike applications. In 2003, SAS is looking to substantially grow its business through continuous improvements leading to more effective and efficient performance on programs, development of product technology road maps and establishing consistent mature processes through the application of Six Sigma principles.

Prior to his current role, Bob has held several key positions within Raytheon, including director of engineering for Air Combat and Strike Systems (AC&SS) and Surveillance and Reconnaissance Systems (SRS), director of engineering for Naval and Maritime Integrated Systems (N&MIS) and manager of the Portsmouth Engineering Laboratory in Portsmouth, Rhode Island. Before joining Raytheon in 1980, Bob served for 12 years as an officer in the United States Navy.

Bob received a Bachelor of Science degree in industrial engineering from Rensselaer Polytechnic Institute in Troy, New York and a Master of Science degree in acoustical physics from the United States Naval Postgraduate School in Monterey, Calif.

The E&TC meets monthly. Additional E&TC members include the Corporate Engineering and Technology staff (George Lynch, Dan Nash, Jean Scire, Pietro Ventresca and Gerry Zimmerman), Mike Teeley (HR), Charlie Case (RLI) and the Raytheon Six Sigma Master Expert for Engineering and Technology.

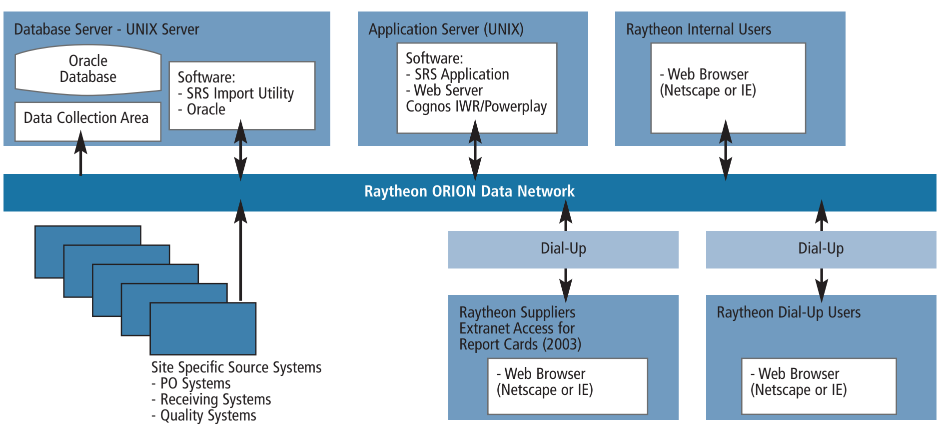
Learn more about the Engineering & Technology star point and the Discipline Engineering & Technology Councils at the Raytheon special interest feature at http://home.ray.com/feature/detc/

- Lee Ann Sousa

Supplier Rating System (SRS)

An enterprise team has succeeded in bringing to life the vision of a One Company system for rating supplier performance. The Raytheon Supplier Rating System (SRS) is available at http://srs.app.ray.com:8080

A cross-functional team representing the Raytheon businesses collaborated to design, develop and successfully deploy SRS meeting enterprise and local site needs. SRS provides all Raytheon employees a rating system to monitor suppliers uniformly at the enterprise, site, commodity and part levels. This ensures that "best value" decisions are made in the supplier selection process. SRS was developed to meet the goal of being world class and provide a road map to excellence to improve our supplier base.



SRS is a web-accessible tool to help engineers, program managers, supply chain management and Product Assurance in the supplier selection process. This tool measures and monitors a supplier's performance. Trends can be analyzed to target and measure the impact of improvements.

SRS brings together the raw data elements from various procurement, receiving and quality/inspection systems across Raytheon.

SRS has the following features:
- Standard Reports
- Drill down to data
- Adhoc Reports
- Analysis Tools
- Raytheon Core Supplier List
- Site Critical Supplier List
- Approved Supplier List
- Dock to Stock Supplier List
- Supplier Performance Multiplier
- Supplier Report Card

The Supplier Performance Multiplier takes the supplier rating and converts it into a factor that can assist in the "best value" supplier selection process.

All Raytheon suppliers will be quantitatively assessed on quality and delivery performance.

All Suppliers

Rating Criteria	Criteria Weight
Quality	60%
Delivery	40%

Additionally, core and critical suppliers will be evaluated on the qualitative attributes.

Core and Critical Suppliers

Rating Criteria	Criteria Weight
Quality	35%
Delivery	25%
Cost	20%
Technology	10%
Responsiveness	5%
Management	5%

Core suppliers receive more than $5M from businesses across Raytheon.

Businesses, sites and programs classify suppliers as "critical" if the products are key in impacting quality, cost schedule, and customer satisfaction.

SRS has a road map to excellence that categorizes suppliers' performance into four levels.

Supplier Performance Levels	Supplier Rating Ranges	Core/Critical Rating Ranges
Superior	97%-100%	98%-100%
Acceptable	90%-96%	90%-97%
Marginal Needs Improvement	80%-89%	80%-89%
Unacceptable Action Required	<80%	<80%

SRS provides Raytheon with a consistent, standard method of rating suppliers to improve the supplier selection process resulting in improved customer satisfaction. The system also provides visibility into all critical SRS data aspects and allows Raytheon to present one face to our supplier base.

Visit the SRS homepage http://srs.app.ray.com:8080 for current system status, user reference manual, training schedule and instructions on accessing supplier reports.

- Cindee Cognetta

SRS points of contact:

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Product Assurance Sponsor

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Project Manager

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Cindee_M_Cognetta@raytheon.com
Business Lead

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Integrated Defense Systems Business Lead

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Intelligence and Information Systems Business Lead

rawittkop@raytheon.com
Missile Systems Business Lead

Teresa_A_Omar@raytheon.com
Network Centric Systems Business Lead

Lynne_E_Mueller@raytheon.com
Space and Airborne Systems Business Lead

THE CUSTOMER (continued)

research labs, and into startup companies and other industrial positions. While this migration fueled the (short-lived) global economic IT boom, it did not bode well for long-term technology innovation. In particular, the lack of investment in fundamental R&D mentioned above is making it hard for DoD developers to master the complexities associated with the move towards large-scale network-centric systems. Thus, as the current generation of technology transitions run their course, the systemic reduction in long-term research funding relative to short-term venture capital funding is seriously limiting the level of complexity of DoD systems that can be developed and integrated using commoditized hardware and software components.

- **Lack of good risk management and modern technology expertise in the DoD workforce.** Throughout this interview I've discussed a number of important software technologies, ranging from QoS-enabled middleware to model-based software tools, patterns, and component frameworks. All of these technologies have been used successfully throughout the DoD. Yet it's remarkable how frequently DoD integrators fail to apply these technologies successfully in practice. Several years ago, the cause of these failures was often rooted in the immaturity of the techniques and tools. As the techniques and tools have matured, however, these failures are increasingly due to lack of good management and education within the DoD software workforce. Unfortunately, the principles, methods, and skills required to develop quality software simply cannot be learned by generalities or platitudes. Instead, developers must learn through experience how to design, implement, optimize, validate, maintain, and enhance reusable software components and frameworks. Only by repeatedly engaging in these activities over time will developers truly internalize good development principles, patterns, and practices. Life-long education is crucial to help improve software developers' skills.

Many of the ideas presented in this interview were shaped by discussions with Rick Schantz, Janos Sztipanovits, Joe Cross, and Frank Buschmann over the past decade.

U.S. Patents Issued to Raytheon

At Raytheon, we encourage people to work on technological challenges that keep America strong and develop innovative commercial products. Part of that process is identifying and protecting our intellectual property. Once again, the United States Patent Office has recognized our engineers and technologists for their contributions in their fields of interest. We compliment our inventors who were awarded patents from October 2002 through March 2003.

BERINDER BRAR
6414360 Field effect transistor and method for making the same

ROBERT C. ALLISON
TAMRAT AKALE
LAWRENCE DALCONZO
JAMES M. HARRIS
HERBERT K. JEW
6414570 Low profile, high isolation and rejection x-band switched filter assembly

WILLIAM W. CHENG
6414615 Excess delay compensation in a delta sigma modulator analog-to-digital converter

ARTHUR A. ENEIM
STEPHEN R. GIBBS
ADAM M. KENNEDY
JANINE F. LAMBE
KENNETH L. MCALLISTER
FARHAD I. MIRBOD
MONESH S. PATEL
6417514 Sensor/support system having a stabilization structure affixed to a side of a platform oppositely disposed from a sensor assembly

TIMOTHY E. DEARDEN
CLIFTON QUAN
JEFFREY J. STITT
6417747 Low cost, large scale RF hybrid package for simple assembly onto mixed signal printed wiring boards

EUGENE R. PERESSINI
6418156 Laser with gain medium configured to provide an integrated optical pump cavity

WILLIAM E. HOKE
PETER S. LYMAN
JOHN J. MOSCA
6368983 Multi-layer wafer fabrication

DAVID C. COLLINS
MARVIN FREDBURG
ROBIN HOSSFIELD
JOHN PUHLHORN
6418856 Passive steering assembly for a guided vehicle

DAN VARON
6420993 Air traffic control system

STEVEN G. BUCZEK
PATRICK J. FITZGERALD
CLIFTON QUAN
FREDERICK C. RUPP
6421021 Active array lens antenna using CTS space feed for reduced antenna depth

JOHN A. DEFALCO
MICHAEL MCPARTLIN
6424224 Auxiliary circuitry for monolithic microwave integrated circuit

BORIS SOLOMON JACOBSON
6424552 Multiphase transformer having main and auxiliary transformers

ROBERT A. WATKINS
6426684 Point detect filter

EKMEKJI, ALEC
GERALD A. COX
PATRICK J. FITZGERALD
SHAHROKH HASHEMI-YEGANEH
DOUGLAS O. KLEBE
WILLIAM W. MILROY
KENNETH NASH
6430805 Method of fabricating a true-time-delay continuous transverse stub array antenna

RONALD E LOVING
6439097 Missile launcher with piezoelectric launcher pulse power source and inductive launcher/missile coupling

LAWRENCE P. DUNLEAVY
STEVEN M. LARDIZABAL
ROBERT S. ROEDER
MATTHEW C. SMITH
6439763 Variable microwave cold/warm noise source

JAN GRINBERG
MICHAEL D. JACK
6441368 Infrared/visible energy protection for millimeter wave bolometer antenna method and apparatus

GARY A. FRAZIER
6441767 Method and system for adjusting a threshold control in an analog-to-digital converter

EDWIN W. DITTRICH
JERRY M. GRIMM
OREN B. KESLER
RANDY J. RICHARDS
6441787 Microstrip phase shifting reflect array antenna

DELBERT LIPPERT
H. BARTELD VAN REES
6443512 Shock absorbing bumper system

ARTHUR J. SCHNEIDER
JAMES G. SMALL
6450442 Impulse radar guidance apparatus and method for use with guided projectiles

ALFRED SORVINO
6450444 Fin lock system

GERALD L. FUDGE
MICHAEL R. LEGAKO
STEWART C. O'DELL
CLINT D. SCHREINER
6452982 Method and system for-down-converting a signal

MICHAEL F. HAMPTON
6453792 Gun trunnion angular-sensing mechanism

GRAY E. FOWLER
G. MICHAEL LIGGETT
JOHN W. OREM
CRAIG E. PREVOST
6453821 High-temperature obturator for a gun-launched projectile

MITCHELL D. GAMBLE
MICHAEL R. WHALEN
6455830 Scanning sensor system with multiple rotating telescope subassemblies

RONALD W. BERRY
CHRISTOPHER L. FLETCHER
ELI E. GORDON
WILLIAM J. HAMILTON, JR.
MICHAEL RAY
6455931 Monolithic microelectronic array structure having substrate islands and its fabrication

J. PAUL A. VAN DER WAGT
6456214 High-speed comparator utilizing resonant tunneling diodes and associated method

GARY A. FRAZIER
6456215 Method and system for quantizing an input

PAUL C. SEO
RICHARD A. STEVENS
MATTHEW J. SULLIVAN
LAWRENCE T. UCHIDA
JOHN P. UTLEY
6456235 Method of predicting the far field pattern of a slotted planar array at extreme angles using planar near field data

WILLIAM P. POSEY
6456238 Dynamic signal routing in electronically scanned antenna systems

JAMES M. FLORENCE
PAUL KLOCEK
DAVID H. RESTER
JOHN A. TEJADA
6456765 Apparatus for separating and/or combining optical signals, and methods of making and operating it

MICHAEL F. BLACK
6456823 System and method for recovering a pilot tone in a local multipoint distribution system signal

HOWARD S. NUSSBAUM
WILLIAM P. POSEY
6459404 DDS spur mitigation in a high performance radar exciter

ROBERT W. KNOX
STEPHEN W. MC CAHON
SCOTT G. MARTIN
ANDREW E. PAUL
6460459 Method and system utilizing a laser for explosion of an encased high explosive

CHUNGTE W. CHEN
RONALD G. HEGG
WILLIAM B. KING
6462882 Light-weight head-mounted display

JEREMIE E. JACKSON
6462889
Conformal-dome optical system with rotationally symmetric stationary optical baffles

JOSEPH M. FUKUMOTO
CHENG-CHIH TSAI
6462891 Shaping optic for diode light sheets

JOHN J. ANAGNOST
PAUL C. KIUNKE
6463365 System and method for controlling the attitude of a space craft

JOSEPH M. FUKUMOTO
6466593 Variable path length passive Q switch

SHIN-TSON WU
6468443 Colorless and low viscosity compounds for low voltage liquid crystal operation

ANTHONY VICTOR HEWITT
NICHOLAS BERT SACCKETTI
6469304 Pseudo-randomized infrared blurring array

MICHAEL L. WELLS
JOHN A. TYSON
6469783 Solid state modulated beacon tracking system

CONRAD STENTON
6469791 Multi-aperture hologram for backwards testing of optical systems

EDWARD L. ARNN
6469792 Method for processing the output of a fiber optic gyroscope to reduce the effects of vibration therefrom

MICHAEL K. CARPENTER
6470064 Extended length counter chains in FPGA logic

RONALD L. MEYER
6470195 Method and apparatus for modeling a smart antenna in a network planning tool

MIKE MEHEN
GARY SALVAIL
MARK KUSBEL
6473051 Elliptic to circular polarization converter and test apparatus incorporating the same for accommodating large axial ratio

CESAR MONZON
6473057 Low profile scanning antenna

JAMES E. BIGGERS
KEVIN P. FINN
RICHARD A. MCCLAIN, JR.
HOMER H. SCHWARTZ, II
6473747 Neural network trajectory command controller

WILLIAM M. HATALSKY
GARY H. JOHNSON
CHRISTOPHER P. OWAN
WAYNE LEE SUNNE
6474594 Output shaft assembly for a missile control actuation unit

MILES E. GOFF
6476704 MMIC airbridge balun transformer

SCOTT HIGGINS
6478213 Fluxless fabrication of a multi-tubular structure

ROBERT J. ADAMS
MICHAEL J. KAISERMAN
MICHAEL B. MCFARLAND
ARTHUR J. SCHNEIDER
WAYNE V. SPATE
STANTON L. WINETROBE
6478250 Propulsive torque motor

ROLAND W. GOOCH
6479320 Vacuum package fabrication of microelectromechanical system devices with integrated circuit components

DAVID F. ROCK
6480272 System and method for in-situ particle contamination measurement using shadowgrams

CONRAD STENTON
6480284 Multiple plane reference mirror for interferometric testing of optical systems

MIRON CATOIU
6483397 Tandem six port 3:1 divider combiner

JOHN C. COCHRAN
JAMES FLOOR
JOHN G. HANLEY
WILLIAM M. POZZO
6483778 Systems and methods for passively compensating transducers

WILLIAM E. TURNER
6484364 Lifting assembly

JAMES G. SMALL
6486827 Sparse frequency waveform radar system and method

RONDALD L. BUCKLES
6486849 Small L-band antenna

MARY D. O'NEILL
WILLIAM H. WELLMAN
6487519 System and method for time-to-intercept determination

WILLIAM E. HOKE
PETER J. LEMONIAS
THEODORE D. KENNEDY
6489639 High electron mobility transistor

R. TODD LINES
RICHARD C. SAVAGE
JIM COLE
6489915 Microwave icing avoidance system

STEPHEN P. LEBLANC
JOSEPH S. PLEVA
WALTER GORDON WOODINGTON
MICHAEL JOSEPH DELCHECCOLO
MARK E. RUSSELL
H. BARTELD VAN REES
CAROLINE BREGLIA
RICHARD P. DONOVAN
6489927 System and technique for mounting a radar system on a vehicle

JAN PAUL VAN DER WAGT
GERHARD KLIMECK
6490193 Forming and storing data in a memory cell

JIN, MICHAEL Y.
LAWRENCE, MICHAEL E.
6492932 System and method for processing squint mapped synthetic aperture radar data

JOSEPH M. ANDERSON
6492947 Stripline fed aperture coupled microstrip antenna

CAROLINE BREGLIA
JOSEPH S. PLEVA
THOMAS W. FRENCH
WALTER GORDON WOODINGTON
MICHAEL JOSEPH DELCHECCOLO
MARK E. RUSSELL
H. BARTELD VAN REES
6492949 Slot antenna element for an array antenna

ROBERT A. MCLEAN
JAMES A. WURZBACH
HAROLD C. GILBERT
LAWRENCE A. SCHATZMANN
GREGORY E. SMITH
THOMAS B. STANFORD
6493638 Sensor apparatus for measuring volatile organic compounds

SHIN-TSON WU
6495066 Dopants for improving the thermal and UV stability of high birefringence liquid crystals

DANIEL SIEVENPIPER
JAR JAR LEE
STAN LIVINGSTON
6496155 End-fire antenna or array on surface with tunable impedance

DEEPAK KHOSLA
6497169 Method for automatic weapon allocation and scheduling against attacking threats

GARY JOHNSON
6497530 Universal flange joint for attaching

SWEENEY, ANTHONY
HEBEISEN, MARK A.
FORBES, ANDREW B.
GINGRAS, RAY
TOTH, JOHN
DELCHECCOLO, MICHAEL J.
LA FAVE, GEORGE
LICCIARDELLO, JOSEPH
6498582 Radio frequency receiving circuit having a passive monopulse comparator

LUIS M. VIANA
MICHAEL JOSEPH DELCHECCOLO
JOSEPH S. PLEVA
MARK E. RUSSELL
WALTER GORDON WOODINGTON
H. BARTELD VAN REES
STEPHEN P. LEBLANC
6501415 Highly integrated single substrate MMW multi-beam sensor

JAMES MCGLATHERY IRION, II
R. THOMAS DOVER
RICHARD E. HODGES
ALLAN R. LOGAN
JOHN C. EHMKE
6501431 Method and apparatus for increasing bandwidth of a stripline to slotline transition

In the News

Raytheon receives Presidential Award for Excellence in Mathematics, Science and Engineering Mentoring

The White House named Raytheon a recipient of the 2002 Presidential Award for Excellence in Mathematics, Science, and Engineering Mentoring. Raytheon was one of six institutions, and, the second company, to receive the prestigious award. The president annually recognizes the people and institutions that have provided broad opportunities for participation by women, minorities and disabled persons in science, mathematics and engineering at the elementary, secondary, undergraduate and graduate education levels. Each award includes a $10,000 grant to provide for continued mentoring work.

"Raytheon is set apart from other Fortune 200 companies in supporting many activities for women and minorities as part of its comprehensive educational and mentoring program," said Legand Burge, Jr., dean of Tuskegee University's College of Engineering, Architecture & Physical Sciences, in a recommendation letter. "Parents and educators are grateful for the selfless contributions of the hundreds of Raytheon employees who volunteer countless hours to train, tutor and mentor students. Without programs such as these, many students may never know that they have the potential to excel in science, mathematics and engineering."

Lynne Bracker, a Raytheon Missile Systems engineering manager, accepted the award on behalf of Raytheon. Greg Shelton, Raytheon vice president of engineering and technology, and Daisy Jenkins, Raytheon Aircraft Company vice president of human resources, were also present at the White House ceremony on March 18, 2003.

Future Events

Third Annual Joint Mechanical and Materials Engineering Technology Symposium

Call for Papers Announced

October 7 – 9, 2003
The Burlington Marriott,
Burlington, Mass.

Sponsored by the Mechanical Engineering and Technology Council (ME&TC).

The symposium will feature three days of presentations, posters, and exhibits in all areas of mechanical/structures and materials/processes technology. It will provide excellent opportunities for exposure by knowledge sharing on the mechanical and materials technologies across Raytheon and to explore innovative ways for increasing Raytheon's future competitiveness through combined efforts.

For more information on the symposium or to submit an abstract, go to the Mechanical and Materials Engineering symposium Web site at http://homebw.sas.ray.com/mmtn/index.html

Processing Systems 6th Technology Expo Announced – *Forging Alliances*

Call for Papers Announced

September 9 – 11, 2003
The Events Center, El Segundo, Calif.

Sponsored by the Digital Electronics Engineering and Technology Council (DE&TC).

This year the Processing Systems Technology Network (PSTN) will continue the tradition for a 6th year of bringing an exciting, high quality technology Expo to Raytheon's engineering population.

Mark you calendar for this much awaited Expo featuring 2 1/2 days of presentations, exhibits, and demos in all areas related to signal and data processing technology. This year there will be a high emphasis on customer attendance as well as customer briefings. Planned topics include: digital receivers, electronics, FPGA/ASICs, middleware, real time software, radiation hardening, optical communication, parallel processing, networked processing, and more.

For more information on the Expo, go to the Processing Technology Expo home page at http://home.ray.com/rayeng/technetworks/tab6/pstn2003/pstn.html

Raytheon Quality Forum Announced – *Mission Assurance*

Call for Papers Coming Soon

September 30 – October 2, 2003
The Marriott Dallas/Fort Worth Airport, Irvine, Texas

Sponsored by the Raytheon Quality Council.

Information will be posted on the Quality home page at http://home.ray.com/quality

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