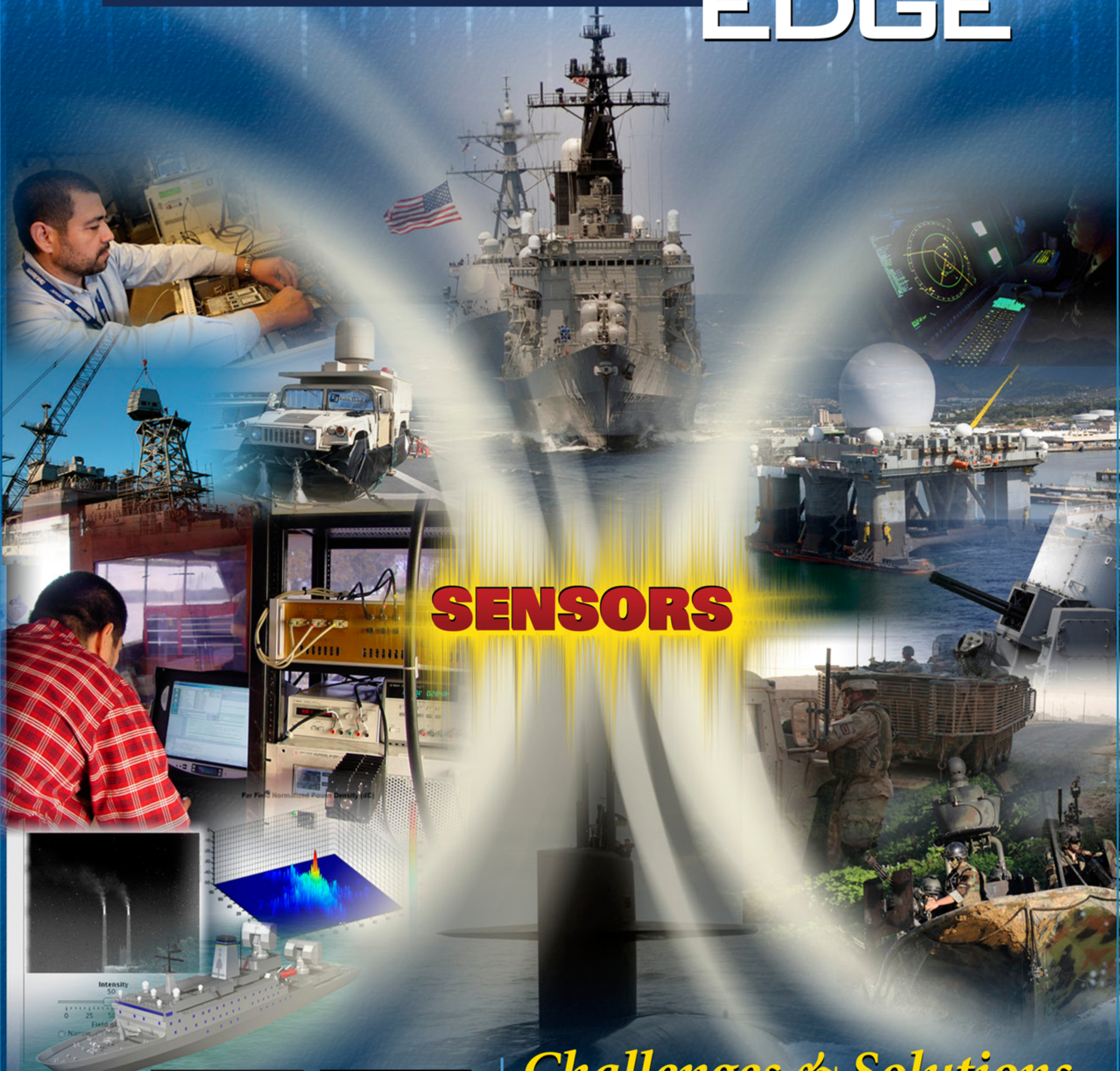
LEADING EDGE

Volume 7, Issue No. 2

NAVAL SURFACE WARFARE CENTER, DAHLGREN DIVISION



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Challenges & Solutions for the 21st Century

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LEADING EDGE

Volume 7, Issue No. 2

SENSORS – Challenges & Solutions for the 21st Century

This Sensors Systems issue of the Leading Edge is the second in a trilogy dedicated to describing the readiness and the challenges facing our team of scientists and engineers in their support of our warfighters.

The previous issue in our trilogy looked at ways we are tackling the problems inherent to harsh electromagnetic effects on the environments at home and abroad. Our upcoming Directed Energy issue will focus on directed energy warfare systems.

We invite you to read more about our success in meeting the challenges and finding solutions for the 21st Century as presented in each edition of the Leading Edge magazine.

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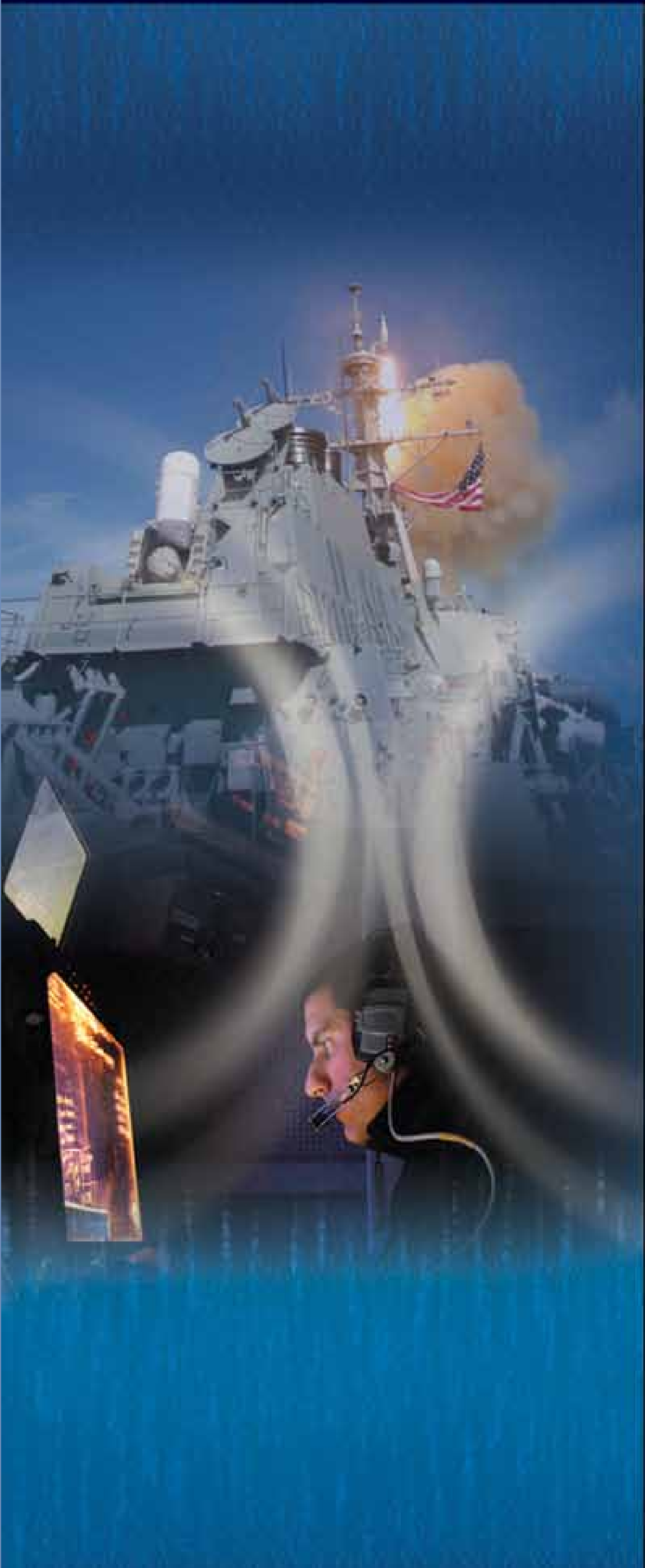

The Leading Edge Magazine is an official, authorized publication of the Naval Warfare Center Enterprise. The purpose of the publication is to showcase technical excellence across the Warfare Center Enterprise, and promote a broader awareness of the breadth and depth of knowledge and support available to the Navy and DoD at NSWC/NUWC.

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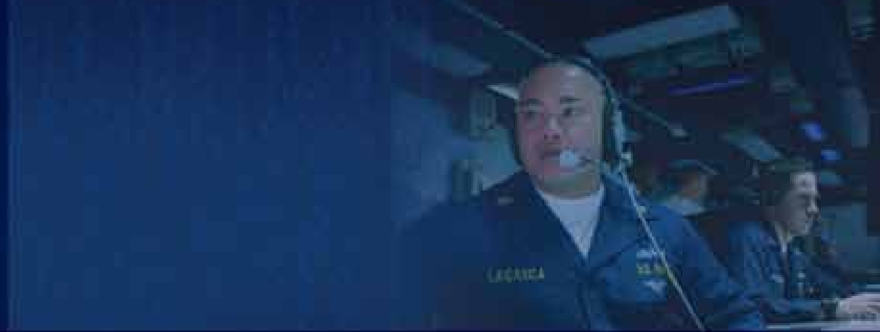
Sensors

Challenges and Solutions for the 21st Century

Introduction



Sensors—Challenges and Solutions for the 21st Century

Rear Admiral James J. Shannon
Commander, NSWC

To engage an enemy, you first must be able to detect it. Consequently, all the firepower in the world won't do our naval warfighters any good if they don't know who or what to engage or where to fire. That's what makes radars and other sensors so critically important. Moreover, these highly technical systems are needed for much more than detecting and engaging an adversary. They are also required for things such as controlling aircraft and missiles, maritime navigation, sensing abnormalities, and tracking the weather. Without these critically important systems, a captain's eyes and ears would be lost at sea.

I am extremely pleased to introduce this edition of *The Leading Edge* magazine, sponsored by the NAVSEA Warfare Centers. The theme for this edition is *Sensors–Challenges and Solutions for the 21st Century*. Indeed, our Navy faces a great many challenges in the coming years. Enemy technological advancements require new countermeasures. New, more capable systems that are interoperable with joint and coalition systems will need to be designed, developed, and deployed, while older systems will need to be replaced. Littoral and riverine warfare require smaller and lighter sensors for the Navy's smaller platforms.

The NAVSEA Warfare Centers welcome these challenges, because we're in the business of providing solutions. We research, develop, test, and evaluate cutting-edge technologies and systems to equip the Navy with sensors on the sea, under the sea, in the air, and on the ground. It is a job that requires a tremendous amount of technical knowledge, as well as strong synergy among our joint warfighters, industry, and academic partners.

I invite you to read about the exciting and important work being accomplished by our Warfare Center scientists, engineers, technicians, and professional support personnel. Due to their tireless efforts and unwavering dedication, they are meeting our constitutional mandate to "provide and maintain a navy." Readiness is our greatest challenge for the 21st century. Readiness is what we ultimately deliver!

Introduction

Developing Innovative Solutions in Sensors Technology

Captain Sheila A. Patterson, USN
Commander, NSWCDD

Sensor systems have come a long way since early radar that centered on basic detection of ships and aircraft for self-protection. Application of sensor technology today spans all areas of theater. Well beyond detecting and tracking ships and submarines, sensors allow us to search for and locate mines, discern lethal environments, and track ballistic missiles. Thanks to expert analysis and engineering, sensor systems are providing accurate tracking at expanded ranges and are being utilized for a broad spectrum of applications. The result is better protection for our men and women in uniform.

From our involvement throughout the years with virtually every phase of development of the SPY-1 radar systems, to our application of open-architecture concepts across systems, NSWC Dahlgren has become a recognized leader in sensor systems integration. Together with our Warfare Center partners represented in the articles that follow, our team is applying state-of-the-art sensor technology and providing at-sea testing to support surface, air, and undersea Navy combat systems.

As ships' designs change and systems become more complex, it becomes increasingly challenging to provide worldwide, high-quality, high-resolution, multiwavelength radar data. We face additional challenges as we face new terrorist threats and ever-changing combat scenarios. From infrared sensors and image processing used for tracking chemical agents, to air traffic control systems, our sensor engineering specialists are diligently working on ways to ensure safety both for the warfighter abroad and for citizens at home.

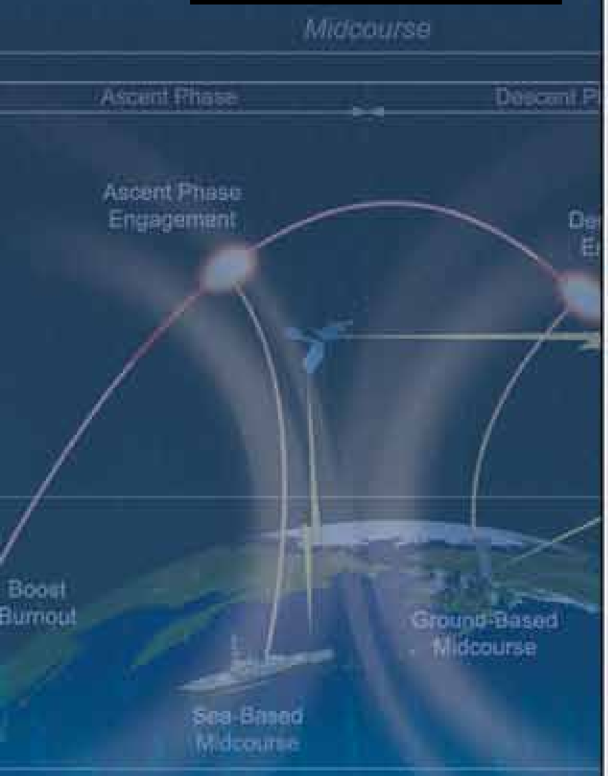
The task of meeting these new challenges and upgrading aging shipboard electronic radar systems has been a continual challenge; but as you will read in this Sensors issue of *The Leading Edge*, our engineers and scientists have found robust solutions and effectively controlled costs. You will also gain a better understanding of the role the warfare centers play in addressing the needs of our warfighters.

I am proud to be Commander of one of the Navy's premier research and development facilities for sensor technology and am confident that NSWCDD will continue its legacy as a leader in sensor systems integration and will meet the needs of the Navy and the nation in the 21st century.

Introduction

Providing Our Navy and Our Nation with the Best Electromagnetic Sensor System Solutions

Mrs. Virginia S. Hudson
Head, Electromagnetic and Sensor Systems Department



Welcome to our Sensors issue of *The Leading Edge*. In the Electromagnetic and Sensor Systems Department at NSWC Dahlgren, Virginia, we are responsible for ensuring that the Navy's surface ship and ground-based radars operate effectively in the operational electromagnetic environment. It's a critically important responsibility necessary for providing naval warfighters with the tools they need to fight, win, and come home safely. It's a responsibility that needs to be done right—right from the start.

With that responsibility in mind, I would like to take this opportunity to highlight the importance of warfighters involving electromagnetic systems engineers in fleshing out sensor system requirements—even before requirements are formally documented. That means warfighters and systems engineers working closely together to develop a common understanding of naval sensor problems and needs driven by operational requirements. It means helping warfighters translate their operational needs into formal, technical systems requirements to increase the likelihood that they will end up with effective sensor systems as a result of moving through the acquisition process. And it means supporting warfighter systems throughout the entire systems' life cycle.

Working together with warfighters ensures that systems are engineered to work well together with other systems. That's what systems engineering is all about. It's not just about the operation of the systems working together in the laboratory environment, but also systems working together in the operational electromagnetic environment. Involving warfighters in the design, development, testing, and evaluation of sensor systems further increases the likelihood that their systems will interoperate with systems from the other services, coalition navies, and other departments and agencies, such as the Department of Homeland Security, the U.S. Coast Guard, and the Federal Aviation Administration.

Warfighters and systems engineers working together helps us better anticipate warfighter needs. So, while they are busy fighting wars and defending our nation, we can best serve their interests by continuing to explore more effective sensor capabilities, systems, and tactics to better arm them for current and future threats. In the end, working together, we provide our Navy and our nation with the very best technologies, systems, and solutions possible, while strengthening our country's national security posture in the process.

An Innovative Radar Clutter Model

By George LeFurjah

Engineers at the Naval Surface Warfare Center (NSWC) Dahlgren have pioneered a new method for modeling the complex environments that our Navy and Marine Corps face when operating radar systems throughout the world. The innovation involves combining radar clutter and atmospheric ducting models, including state-of-the-art meteorological modeling. This is a groundbreaking effort—the first of its kind anywhere. The result is the Littoral Clutter Model (LCM). Although originally intended strictly as a model for shipboard radars, LCM has been extended to also apply to land-based radar applications. This article describes this new model and shows how it can be used to enhance Navy target detection, tracking, and discrimination capabilities in littoral environments.

Background – Complex Environments

There are two aspects to what is meant by environment: objects that are in the field of view of the radar and the atmospheric conditions that affect how those objects appear to the radar system. Radar operates by radiating electromagnetic energy from a focused antenna in the direction of some interesting targets; those targets are just a subset of the many objects in the radar's field of view. That energy, typically in the form of short bursts or pulses, is concentrated by the antenna into a relatively narrow part of that field of view. When the energy is reflected from an object, it rebounds in the direction of the radar antenna and is then received and processed by the radar. Atmospheric conditions affect the path of that energy in two ways. Energy is absorbed by the atmosphere, and the path is altered by atmospheric refraction and, to a lesser degree, diffraction around intervening objects. The absorption process reduces the amount of reflected energy that the radar can receive, making it a little harder to detect the targets. Refraction is the more troublesome of the effects. Simple refraction changes the apparent direction of the targets. When the atmosphere is sufficiently layered in temperature or humidity, a refractive layer can act to bend the path down to where the energy reflects back and forth between the surface and the layer. An analogy of this effect is the optical refraction that occurs when a person looks at a fish underwater. The layer, or the boundary between the water and the air, refracts the light, bending it such that the fish is on a different line to the eye than is apparent. If the person looks at a shallow enough angle, the surface no longer appears transparent, but rather it appears to be like a mirror. A similar refractive bending occurs in the atmosphere when the temperature, humidity, or air density forms layers. Under certain conditions, a layer above the radar can act as a partially reflective surface in which the pulse can be reflected back towards the surface, and by virtue of multiple reflections, the pulse can travel for great lengths along the surface. In the absence of such a condition, the pulse would travel in nearly a straight line and, because of the earth's curvature, diverge from the surface. A depiction of the atmospheric boundary layer is shown in Figure 1.

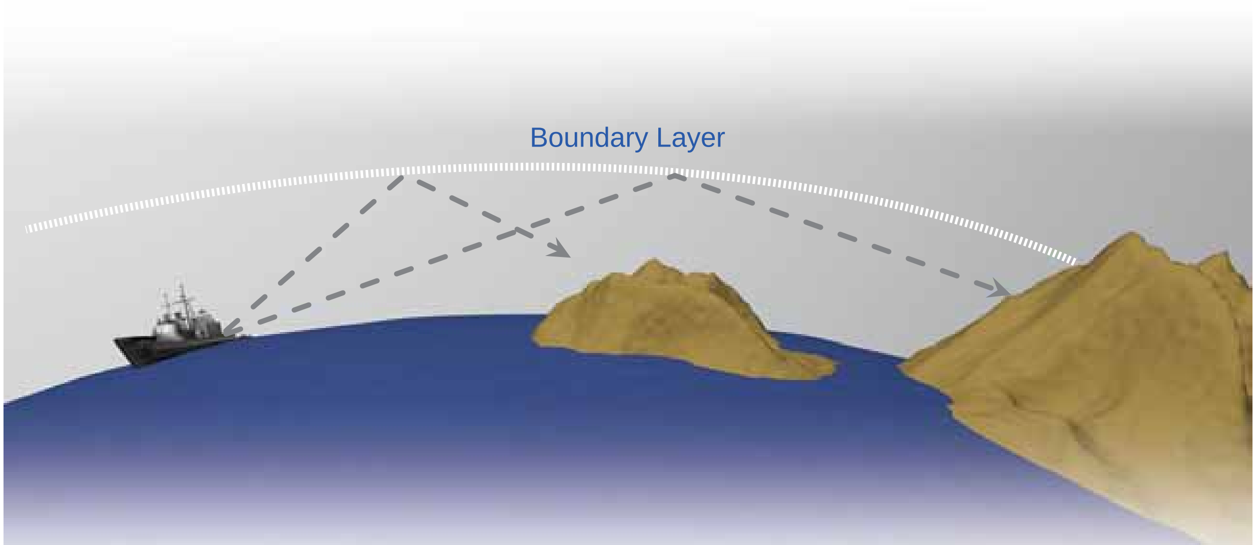


Figure 1. Atmospheric Boundary Layer

Because it is analogous to a waveguide, this condition is called atmospheric ducting, or simply ducting. This situation is not unique to radars. If you listen to radio in these conditions, you can sometimes pick up stations far away from your local area, sometimes hundreds of miles over the horizon from your location. The atmosphere does not have cut-and-dried simple layers, and the surface of the earth is not a flat, featureless plain. Thus, these complications make the prediction of how that path is altered a nontrivial exercise.

Clutter, simply put, represents targets that are of no interest to the radar's mission, which is typically to detect and track moving air or ground vehicles. Of course, one radar's clutter might be another radar's target. Weather radar, for example, tries to detect storm clouds and measure their velocity. Military radar would consider storm clouds to be clutter. Clutter is named for the appearance it presents on a typical radar display. Instead of simple target blips, the operator sees a scattered hash of signals. Some examples of clutter are rainstorms, sea surface scatter, land, trees, mountains, and buildings. Clutter has a number of undesirable effects on radar's operation. It obscures targets by overpowering the target's signal and is often simply a bigger target than a boat, aircraft, or missile. In other words, clutter reduces the ability to detect targets of interest. This is the probability of detection problem. The other key problem with clutter is that it can look like a target; it, too, can be detected and tracked. This is called the false alarm problem. When radar automatically detects and tracks targets, clutter can overload the system with false tracks. Once again, if it were weather radar, these storms tracks would not be false at all. Whatever the perspective as to what constitutes clutter, it is a problem for radar that must be acknowledged, accounted for, and dealt with.

When the atmosphere enhances propagation on the surface, then clutter—which is almost entirely a near surface phenomenon—can present returns from many miles, even hundreds of miles, away from the radar. This long-range and extended clutter is much more of a problem in both detection and false alarms. Figure 2 depicts recorded radar data from USS *Lake Erie* operating in the Persian Gulf. In this depiction, ducting conditions caused land clutter to be visible from hundreds of miles away. The radar is generating a picture of the whole shoreline of the Gulf, even inland in Iraq.

Littoral Radar Clutter Model

Coastal (or littoral) combat operations are the major drivers for current U.S. Navy radar system design. As we have seen, coping with clutter and atmospheric considerations is crucial to the task of providing adequate new radars. Consequently, adequate simulations of the environments faced by these new radars are crucial for radar system design and radar system performance analysis. In the current acquisition environment, adequate simulations are also a crucial adjunct to expensive, live system testing. When based upon complex spatially and temporally inhomogeneous atmospheric propagation prediction, realistic littoral clutter predictions are useful from all of these perspectives. When used in conjunction with radio frequency (RF) scene generation, these models can even replace some radar performance specification testing. All these considerations led to the development of LCM at NSWC Dahlgren.

LCM is a synthesis of several elementary models—a model of models (see Table 1). LCM models surface clutter from the land and the sea, while using up-to-date topographical data. It also models the atmosphere's effect by modeling the refractive properties of the atmosphere and the propagation of the radar pulse through that atmosphere using a mathematical process called parabolic equation computation. NSWC Dahlgren pioneered the use of mesoscale numerical weather prediction (MSNWP) technology to generate a 3-D picture of the atmospheric refraction.

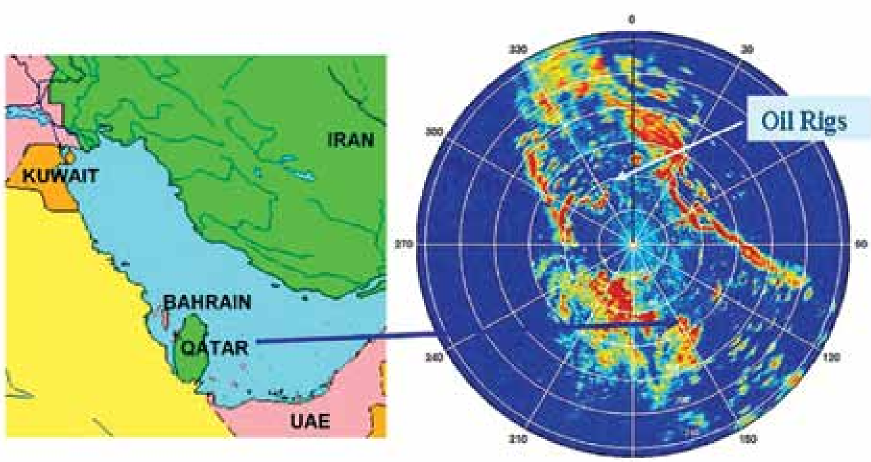


Figure 2. Map of Recorded Radar Data from the Persian Gulf with the Geographic Map of the Region

Table 1. Littoral Model Component Models

DTED Level 1 Terrain Data—to model Land Topography
AVHRR Global Land Cover Database—to model Land Surface Reflectivity Characteristics
Billingsley Empirical Land Clutter Model—for Land Radar Reflectivity (σ^0)
GTRI Sea Clutter Model—for Sea Surface Reflectivity (σ^0)
JHU/APL TEMPER Radar Propagation Model—to compute Propagation Factor (F^4)
COAMPS—Coupled Ocean/Atmosphere Mesoscale Prediction System to model the atmosphere

Component Model Descriptions

Input Data

Variable height, site-specific terrain, is computed with terrain contours from Digital Terrain Elevation Data (DTED) files provided by the National Geospatial-Intelligence Agency (NGA).

The United States Geological Survey (USGS) provides a global land cover database, Advanced Very High Resolution Radiometer (AVHRR), with 24 terrain type classifications with a latitude and longitude worldwide reference. The terrain types are correlated with the DTED data to associate appropriate electrical properties and surface roughness values with each patch of terrain. Together, these data provide the terrain heights, electrical properties, and surface roughness for each clutter patch along each radar propagation path. In addition, they provide inputs for the computation of clutter reflectivity.

Surface Clutter Models

LCM is primarily a statistical model, meaning that the clutter is computed based upon known statistical variations rather than on precise modeling of every object that might be in the radar field of view; but the statistics are computed based upon the nature of the surface on the earth at specific locations. In order to model backscatter from patches of terrain or ocean surface, it is usually necessary to employ an empirical clutter model, rather than a conceptual or physics-based clutter model. This is especially true in the case of low-angle radar clutter, where this model applies. The empirical models employed provided, distributed clutter amplitude statistics, in terms of Weibull means and spreads, to represent the normalized clutter reflectivity, σ^0. The radar cross section of a patch of surface clutter is computed as σ^0 times the propagation factor, multiplied by the area of the clutter cell. The Navy-Standard Georgia Tech Research Institute (GTRI) model provides σ^0 for sea clutter, and the low-angle radar empirical land clutter model designed by J. Barrie Billingsley at Massachusetts Institute of Technology (MIT) Lincoln Laboratory provides σ^0 for land clutter.

The Billingsley land clutter model was chosen for very low-angle radar land clutter. It is based upon extensive land clutter measurements conducted by MIT Lincoln Laboratory of a large range of terrain types over a range of depression angles and surface slopes, for both vertical and horizontal polarization, and from very high frequency (VHF) to X-band, approximately 200 MHz to 10 GHz.

Atmospheric Propagation Model

Parabolic equation computation provides a fast solution to Maxwell's equations. Although the details of this process are beyond the scope of this article, this technique allows the modeling of the atmospheric propagation over a realistic, topographically complicated surface. The atmospheric refractivity may vary with respect to range and height. The surface boundary may be ocean or variable height terrain of range-varying composition. The Tropospheric Electromagnetic Parabolic Equation Routine (TEMPER) is a parabolic equation code that was developed at the Johns Hopkins University Applied Physics Laboratory (JHU/APL). It uses refractivity profiles, which are refractivity as a function of height and ground location, as well as surface roughness derived from surface land cover to compute radar propagation.

Mesoscale Numerical Weather Prediction (MSNWP)

The weather reports we see on the news every night are predicated upon complex computer simulations of the atmosphere. These models cover very large areas of the earth and are called synoptic weather prediction models. MSNWP is a very similar process but computed for much smaller areas. To get an idea of the scope, synoptic models might cover thousands of miles; mesoscale models cover a few hundred. The idea of using MSNWP to generate realistic depictions of site-specific atmospheric conditions and combining them with site-specific clutter is a unique development innovated at NSWC Dahlgren.

MSNWP is the numerical modeling of the physical/dynamical nonlinear differential equations that govern atmospheric flow. Initial conditions are developed by combining previous forecasts with new meteorological observations through a process termed ***data assimilation***. Simultaneous numerical integration of these equations provides a prognostic capability out to 72 hours. MSNWP models are typically 100 × 100 km and nested within a global forecast model. The lateral boundary conditions for the MSNWP models are derived from the larger scale global model. MSNWP models employ horizontal grid resolutions sufficient to resolve circulations produced by local surface features, such as air/land/sea boundaries and topography. Advances in computing power allow for horizontal resolution as fine as 1 km. In order to provide this resolution over an area of interest, MSNWP models are multi-nested, with the resolution becoming finer from nested grid to the next nested grid. Resolving near-surface refractivity is one of the most challenging applications for MSNWP, where refractivity profiles are derived from the MSNWP model profiles of pressure, temperature, and humidity. Research and development classes of MSNWP models currently may provide 10 m vertical resolution in the first 100 m near the surface.

MSNWP currently provides a qualitative, four-dimensional—three spatial dimensions and time—refractivity field in the littorals. The MSNWP model will resolve the local circulation that produces the current anomalous propagation regime. The phase of the circulation, the height of the atmospheric boundary layer, the vertical gradients of temperature and water vapor, and the sea surface temperature will be slightly different from those measured by in situ meteorological instrumentation. This will result in some duct height and strength errors but will provide insight into the varying structure of coastal refractivity.

The Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) is the MSNWP model that has been chosen for use in LCM. It was developed by the Marine Meteorology Division of the Naval Research Laboratory (NRL) in Monterey, California.

Oil Rig Platform Clutter

Although the Billingsley statistical data (referenced in Table 1) does a good job of predicting the occasional large-amplitude return from land clutter, it will not predict the return from discrete objects that are permanently installed away from shore. The biggest of these in terms of reflecting radar energy are oil-drilling and ship-loading platforms. The Vector Vertical Obstruction Database (VVOD), developed and maintained by NGA, provides the locations of these oil rigs. By using this database and modeling the radar return from these rigs as analogous to a large ship, LCM has been modified to include a discrete clutter layer that reveals the radar return as an overlay on the basic LCM clutter picture. Figure 3 shows an example oil-drilling platform.

An Example Use of LCM

Figure 4 illustrates an example that shows the realistic portrayal of clutter possible with the LCM clutter simulation. For this example, the model was centered at the latitude and longitude coordinates of USS *Lake Erie* at the moment clutter was recorded. That data is shown in the Plan Position Indicator (PPI) display on the right side of the figure. The COAMPS weather prediction code was used to generate a prediction of the atmospheric conditions at the time of the data collection. The COAMPS data for this study were generated at the NSWC Dahlgren. As can be seen on the left side of the figure, the LCM-generated data is a very reasonable depiction of what was actually seen aboard ship. The shoreline, islands, inland mountains in Iran (to the top right of the PPIs) and the oil rigs are seen clearly in both pictures. Some of the details—such as low-level sea clutter near the ship—are missing from the model. Currently, engineers and meteorologists at NSWC Dahlgren and NRL Monterey are working on improvements to the resolution of COAMPS near the surface, which hopefully, will increase the accuracy of model results even more.

As a result of these innovative radar-clutter modeling efforts, Navy warfighters in the future will be better armed with enhanced target detection, tracking, and discrimination capabilities in littoral environments.

Figure 3. An Example Oil Drilling Platform

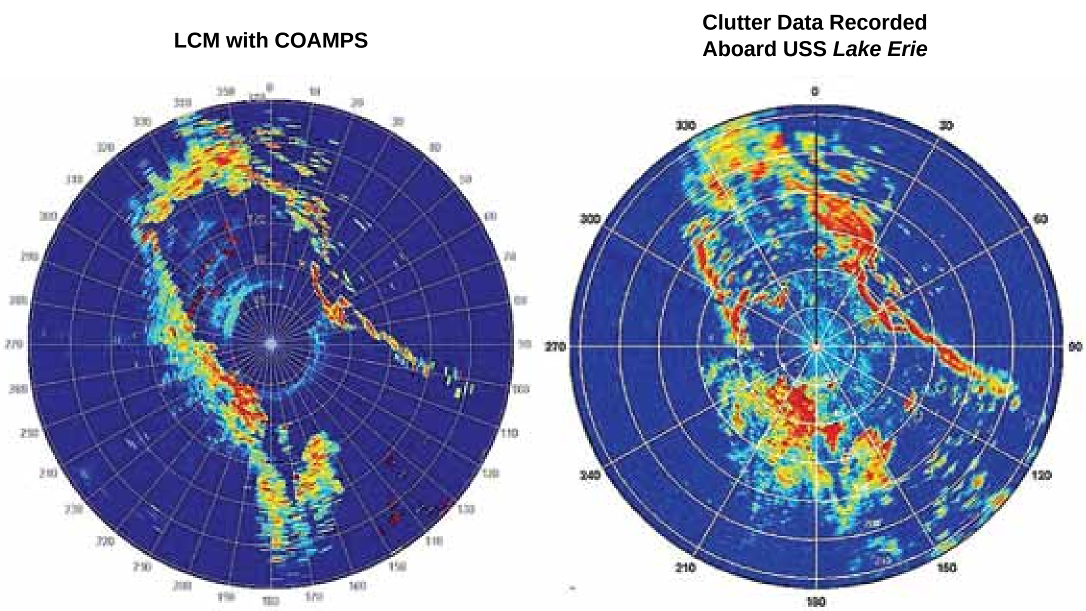
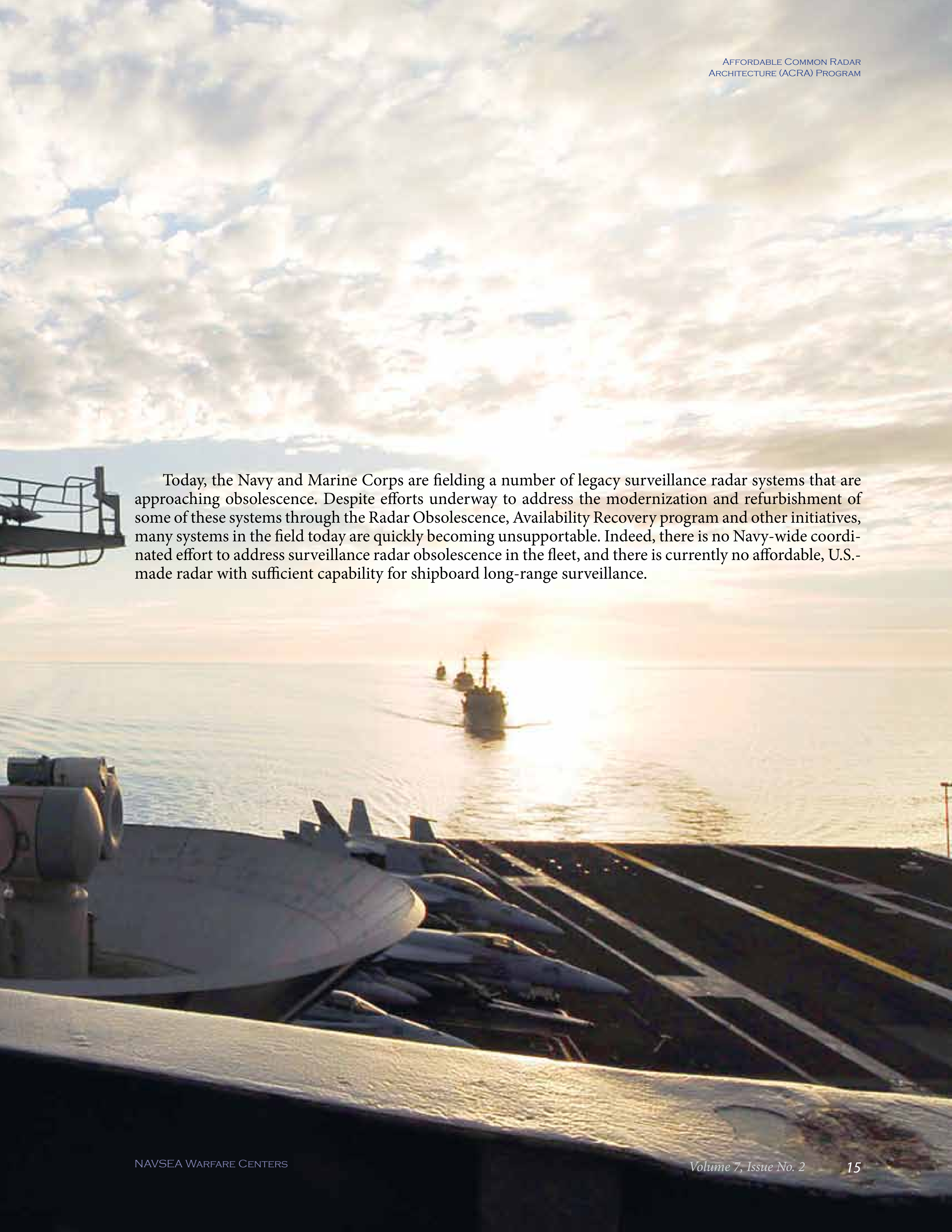


Figure 4. Littoral Clutter Model Simulation of Clutter Seen Aboard USS *Lake Erie*

Affordable Common Radar Architecture (ACRA) Program

By Stephen G. Thomas



Today, the Navy and Marine Corps are fielding a number of legacy surveillance radar systems that are approaching obsolescence. Despite efforts underway to address the modernization and refurbishment of some of these systems through the Radar Obsolescence, Availability Recovery program and other initiatives, many systems in the field today are quickly becoming unsupportable. Indeed, there is no Navy-wide coordinated effort to address surveillance radar obsolescence in the fleet, and there is currently no affordable, U.S.-made radar with sufficient capability for shipboard long-range surveillance.

Legacy surveillance radar systems approaching obsolescence include the AN/SPN-43, AN/SPS-48E, TPS-59(v)3, AN/TPS-75, and AN/SPS-49(V). They provide the fleet and the Marine Corps with a range of capabilities necessary for air traffic control and combat operations. Moreover, in addition to these systems approaching obsolescence, much of the current supply has been refurbished. Systems approaching obsolescence are shown in Figure 1.

In light of the need for timely and affordable system modernization across the board, the Office of Naval Research (ONR) initiated a Future Naval Capability (FNC)-funded program and tasked the Naval Surface Warfare Center, Dahlgren Division (NSWCDD) with oversight, technical direction, technology development, and integration. The Affordable Common Radar Architecture (ACRA) program, kicked off in FY09, is a risk-reduction effort with the goal of developing a scalable, common architecture with supporting technologies applicable to long-range surveillance radars. For the warfighter, ACRA represents improved performance in the littoral regions with a reliable, supportable, affordable system. The ACRA program will provide capability for both rotating phased arrays and multifaced fixed arrays based on a core group of common, scalable components. These

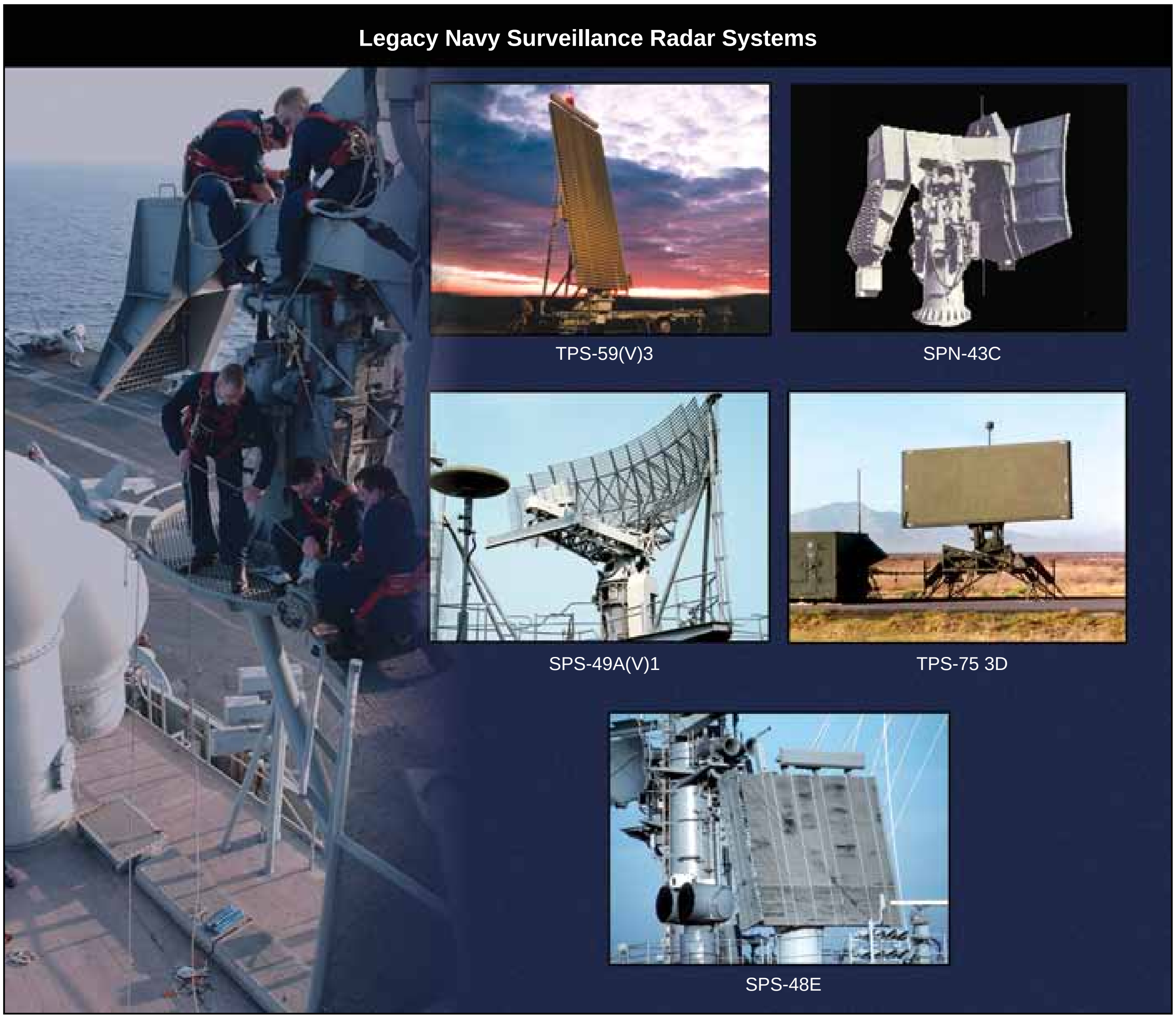


Figure 1. Legacy Surveillance Radar Systems Approaching Obsolescence

components include the radar array's mechanical structure and electrical signal network, digital receivers, waveform generators, and data processor. Separate transmit (TX) and receive (RX) arrays flood a search region with a single, wide TX beam and multiple, digitally formed, simultaneous RX beams. The digital receivers are located on the array structure, while the beamforming and TX circuitry is located below decks. Figure 2 shows a conceptual drawing of these components.

The 5-year program plan calls for the design and construction of an affordable Advanced Development Model (ADM) risk-reduction, rotating radar prototype. Unlike many current radar systems, the ACRA radar will comprise two separate antenna structures—a TX array and an RX array—in contrast to a single, common TX/RX array. This has the potential to lower overall system cost through a number of innovative array design techniques currently being investigated by NSWCDD and the ACRA team. For example, a low-power, air-cooled RX array printed circuit board design and a small, passive TX array are currently undergoing cost and performance trade studies. In parallel with array development, NSWCDD is involved in technology development efforts aimed at producing cost-effective, scalable receivers; waveform generators; and signal processors based on an open-architecture specification developed by NSWCDD for the ONR Digital Array Radar (DAR) program. Once the array and technology risk-reduction and development efforts are completed, the entire system will be integrated into an ADM prototype for testing and demonstration in FY13. These ACRA system components will leverage DAR technologies and cost-saving concepts. ACRA system components are shown in Figure 3.

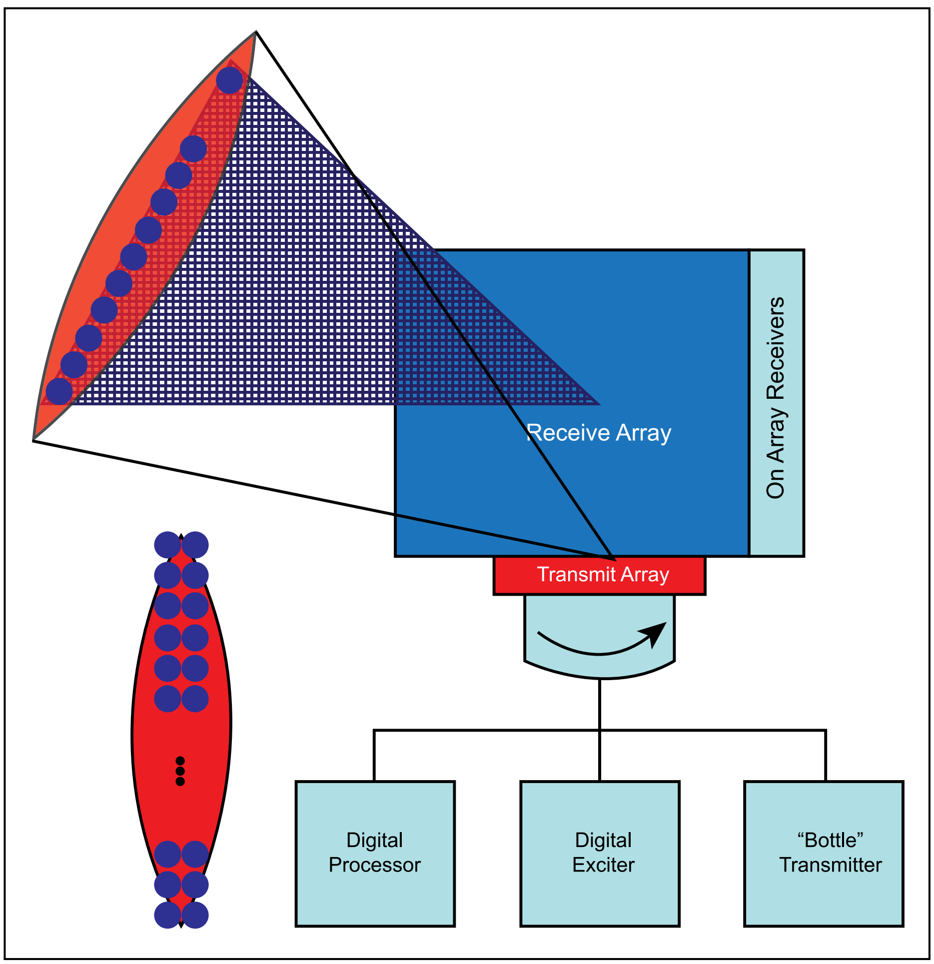
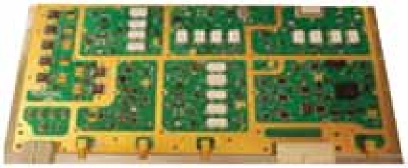
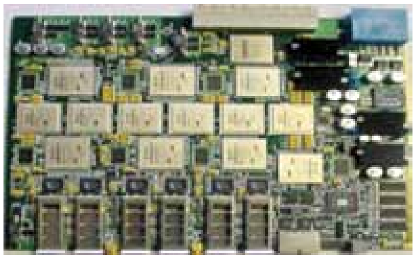


Figure 2. The ACRA System Concept



Frequency Synthesizer

Frequency Down Converter



Digital Beamforming
Circuit Board

Printed Circuit Board
Antenna Array

Figure 3. ACRA System Components

The performance requirements for the ACRA system must span the requirements of multiple legacy systems. Indeed, the overarching goal and primary challenge facing the program is to design and build an affordable, scalable system capable of replacing multiple legacy systems. Chief among the requirements is the capability to accurately search a large volume at long range; to update this search at a sufficiently high rate to track objects of interest; to mitigate the effects of sea clutter and anomalous atmospheric conditions on radar performance; and to possess the capability to mitigate hostile jamming. Trade studies are underway to optimize the system architecture to demonstrate scalable system performance and system cost to meet the needs of various potential end users. For example, to effectively search a large volume (at long range) with a sufficient update rate requires a high-power TX antenna emitting a wide beam, coupled with a large RX antenna forming multiple, simultaneous RX beams. NSWCDD RX antenna trade studies are examining array architectures and their resulting patterns. Figure 4 shows the generation of a low sidelobe pattern based on a triangular element grid, further based on a staggered arrangement of circuit board panels.

NSWCDD is also leading the way in defining the system architecture and subsystems requirements forming the backbone of the entire ACRA system. The subsystem technologies include digital receivers, waveform generators, reference clocks, and beamformers. The physical digital and analog interfaces between these subsystems are defined within an open-architecture design concept based on open, standard, nonproprietary protocols and signal formats, as initially developed and defined by ONR's DAR program. The benefits of an open-architecture design are many, including subsystem development in a competitive environment to reduce system cost; the use of relatively inexpensive, readily available commercial products and standards; ease of hardware upgrade (technology refresh) during the life of the system; and ease of adding future functionality (technology insertion) once the system is deployed.

The Navy's current fleet of shipboard long-range surveillance radars is approaching obsolescence. Moreover, future naval radar systems are expected to be largely digital in design. The ACRA program represents an opportunity for developing a new, modern, affordable, and scalable Navy radar asset based on a digital open-architecture concept. Over the next 5 years, NSWCDD scientists and engineers will be working to make this concept a reality. As a result, Navy and Marine Corps warfighters will experience improved performance in a reliable system for shipboard surveillance and combat support.

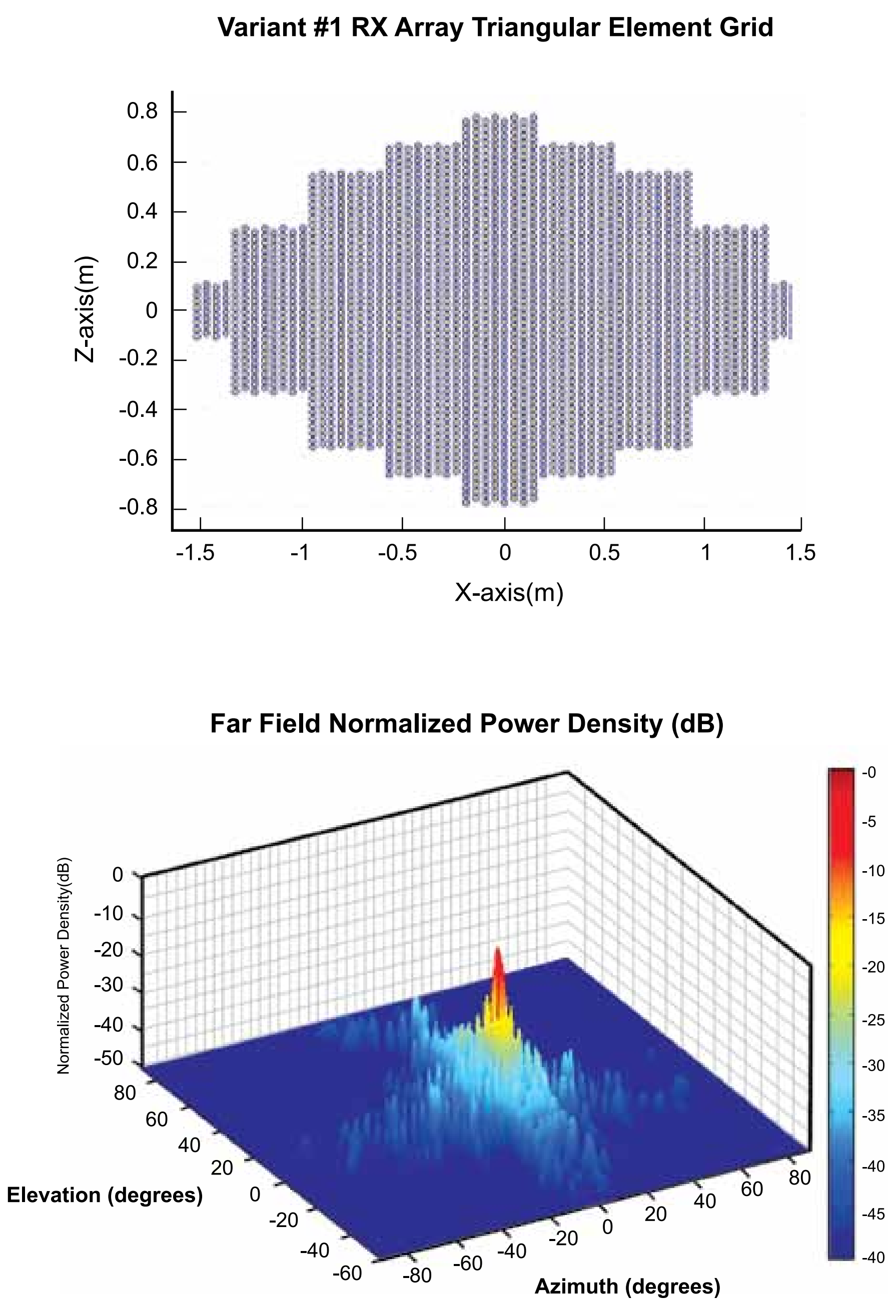
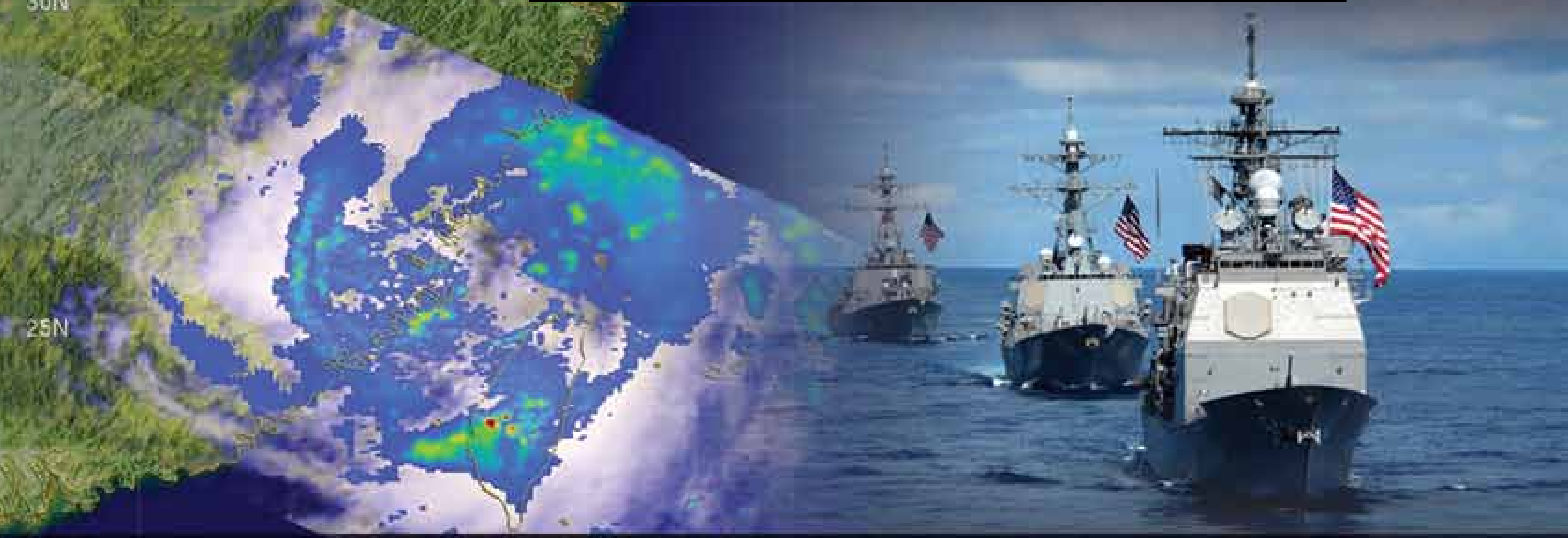


Figure 4. Low Sidelobe Pattern Based on a Triangular Element Grid, Further Based on a Staggered Arrangement of Circuit Board Panels



Littoral Radio Frequency System Performance Forecasts

By Robert E. Marshall

Radio frequency (RF) propagation refers to the impact of the atmosphere on RF energy as it flows through the atmosphere between antennas. RF propagation is influenced by the clear atmosphere, rain, fog, cloud, snow, ice, and electron densities found in the ionosphere. Propagation in the clear atmosphere can significantly impact RF system performance. Refraction is the bending of light energy or RF energy. Refraction at optical wavelengths is observed when one inserts a pencil in a glass of water and the pencil appears bent at the top of the water column. The bending of light energy by small raindrops produces rainbows. You cannot see RF energy as it is bent in the clear atmosphere, but on a perfectly clear day with no visible clues from the atmosphere, radar may suffer severe refraction and subsequent poor mission performance. As RF energy leaves the antenna, it is bent by the atmosphere in ways that can easily refract it away from the intended target. RF energy is especially attracted to areas in the atmosphere with high humidity or low temperatures. Radar operators who do not account for refraction can be easily fooled by what the radar signal is telling them about targets.

Navy surface radars and communication systems operate in a shallow layer of the atmosphere called the marine atmospheric boundary layer (MABL). The MABL can extend from the sea surface up to as high as 1000 m—a complex environment where humidity, temperature, and refraction vary wildly. The MABL is drastically more complex within 100 km of the coast than it is over an open ocean. RF energy can be bent or refracted in various ways in the MABL. Figure 1 illustrates the four RF refraction categories.

Standard propagation or refraction has roots in the U.S. National Advisory Committee on Aeronautics (NACA) 1922 definition of a standard atmosphere. The NACA standard atmosphere was necessary to provide a standard for aircraft performance. Unfortunately, the standard atmosphere is more likely to be found above the MABL and typically provides a false impression of radar performance within the MABL. Super-refraction occurs when the RF energy is bent just enough such that it hugs the curvature of the earth. RF energy travels great distances in the MABL when it is super-refracted, allowing radars to see targets and communications systems to operate at abnormally long ranges. This propagation benefit is often complicated by the potential accompanying liability of folded land clutter and radio frequency interference (RFI). Subrefraction occurs when higher humidity is found at the top of the MABL, and RF

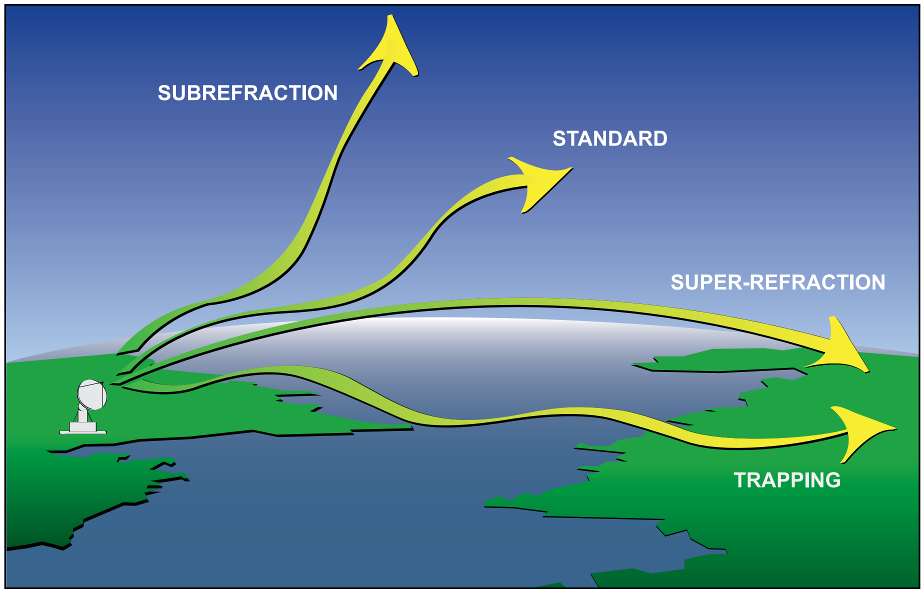


Figure 1. RF Propagation or Refraction Categories

energy rapidly bends away from the earth's curvature. Subrefraction is a relatively rare event, but when subrefraction occurs, radar detection of targets in the MABL becomes significantly more difficult, and the naval surface platform becomes more vulnerable to an approaching target. Trapping or ducting occurs when higher temperatures are at the top of the MABL, and higher humidity is at the bottom of the MABL. The RF energy is trapped or ducted between the top and bottom of the MABL and bounces back and forth as it propagates away from and back to the antenna. Ducting develops radar holes or skip zones where targets cannot be detected, and it also produces areas of sea clutter, where targets are difficult to detect.

To make matters worse, the MABL is forever evolving, driven primarily by the land/sea temperature difference. During daylight hours, the sun heats the land much faster than the ocean often leading to a sea breeze, as the model in Figure 2 demonstrates. Warm, dry air flows offshore at the top of the MABL, and cool, moist air flows onshore at the bottom of the MABL. After the sun sets, the circulation tends to reverse as a land breeze with warm, dry air flowing offshore near the sea surface and cool moist air flowing inshore aloft. As this typically 24-hr cycle progresses, the refractivity field in the MABL is constantly readjusting and constantly impacting RF system performance.

Accounting for these constantly varying refractive and propagation influences on RF system performance is essential for operations, acquisition engineering, and prototype RF system testing. The use of weather balloons, helicopters, rocket weather sounding systems, unmanned aerial vehicles (UAVs), and weather buoys have all been employed to document the refractive environment in the littorals. These are logistically difficult, expensive, and lack the ability to forecast what will happen in the future.

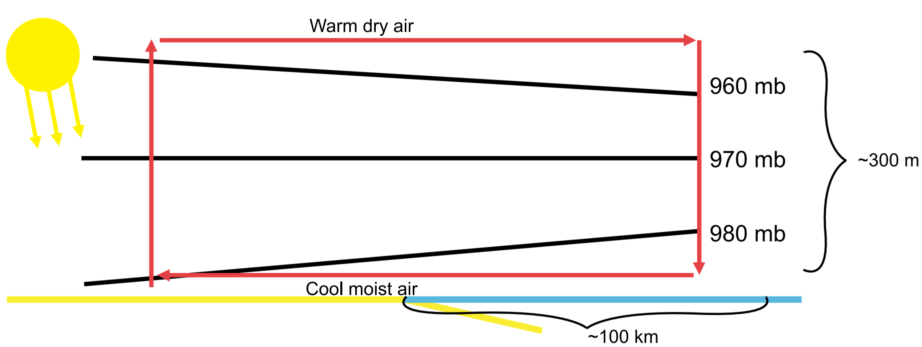


Figure 2. Sea Breeze Circulation

The Naval Surface Warfare Center, Dahlgren Division (NSWCDD) has a 15-year history of research and development in clear-air refraction of RF energy and how it impacts radar and communication system performance. For the last 5 years, NSWCDD has exploited the rapidly maturing technology of numerical weather prediction (NWP) to capture the four-dimensional (4-D) refractive structure of the MABL. NWP is displayed daily by television broadcast meteorologists as time-lapse forecasts of rainfall, clouds, or wind. This same NWP technology can be employed to forecast refractivity in the MABL. NWP models are globally locatable, provide a 48- to 72-hr forecast, and take into account all the land/sea characteristics that drive the evolving MABL refractive structure. There are dozens of NWP models used by military and civilian agencies around the world. NSWCDD runs the Coupled Ocean Atmosphere Mesoscale Prediction System (COAMPS). COAMPS is the U.S. Navy medium-scale NWP model developed and supported by the Marine Meteorology Division of the Naval Research Laboratory in Monterey, California (NRL-MRY). COAMPS products are run operationally by the Fleet Numerical Meteorology and Oceanography Center (FNMOC), also in Monterey, California, for many locations around the globe in support of fleet operations.

NSWCDD's COAMPS system consists of two Linux clusters. The research and development cluster named Bean resides at NRL-MRY and supports COAMPS improvements by way of a scientific collaboration between NSWCDD and NRL. As these improvements are validated, they are ported to the operational cluster at NSWCDD named Dutton/Mesos. Dutton/Mesos supports RF test beds at Wallops Island, Virginia, and the Potomac River Test Range (PRTR) at Dahlgren. Example COAMPS model output for both locations is shown in Figure 3. Figure 3 displays temperatures at 2 m above the surface and wind flags at 10 m above the surface. The 1-km horizontal resolution is indicated by the locations of the wind flags. Dutton/Mesos is also capable of simultaneously supporting models at four other global locations.

These same COAMPS models are capable of forecasting refractivity in the MABL. Thus, refractivity is provided every kilometer, every hour out to 48 hr in the future through the depth of the MABL.

The refractivity fields by themselves are of little use to RF engineers until paired with modern RF system models. RF system performance models have been modified in recent years to accept NWP 0- to 48-hr refractivity forecast fields. The coupled model pair can lead to 0- to 48-hr RF system performance forecasts as illustrated in Figure 4.

The Advanced Refractive Effects Prediction System (AREPS) is developed and supported by the Propagation Research Branch of the Space and Naval Warfare Systems Command (SPAWAR)/San Diego. AREPS ingests COAMPS refractivity fields and specific RF system specifications, and computes system performance. Figure 5 is an example of a combined COAMPS/AREPS radar performance forecast for a notional S-band radar located along the edge of the Gulf Stream off the Eastern Shore of Virginia. The white radials along each bearing indicate the range at which a

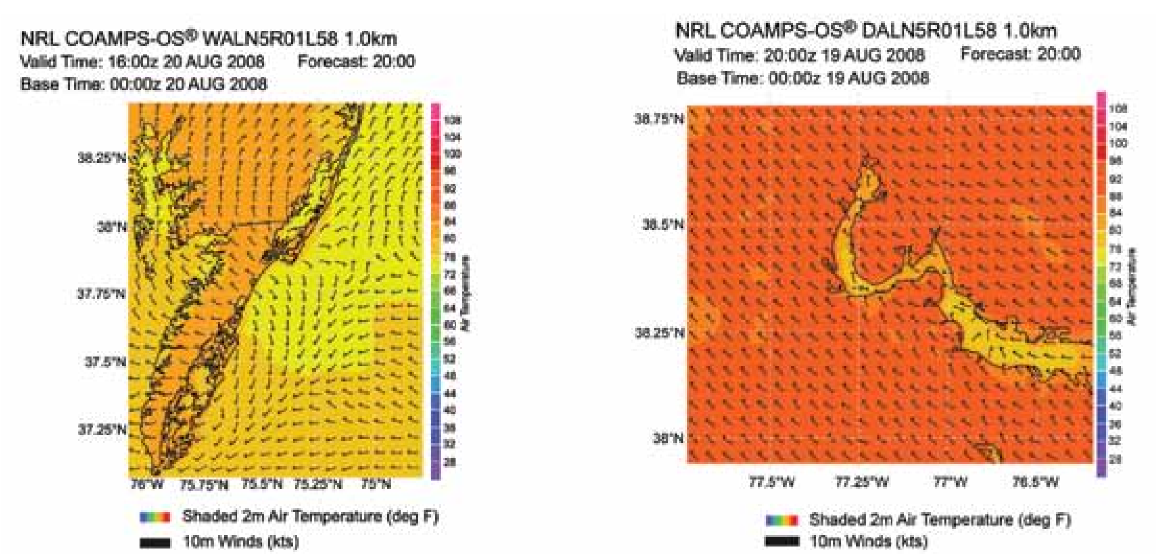


Figure 3. COAMPS Models Over Wallops Island (a) and the PRTR (b) (Wind flags at 10-m ASL and air temperatures at 2-m ASL are displayed.)

notional target 10 m above the surface is detected by the notional S-band radar. The variation in detection range with bearing is indicative of how the refractivity field can vary in the MABL. The red ring indicates the detection range in a standard atmosphere. The reduced detection ranges relative to a standard atmosphere indicate areas of subrefraction to the north of the ship. The extended detection ranges southwest of the ship are due to an area of super-refraction. These azimuth-dependent predictions of radar detection range are due primarily to the spatial changes in MABL structure as it reacts to the significant changes in sea surface temperature found along the edge of the Gulf Stream. All these atmosphere and sea surface impacts are captured by COAMPS.

Refraction—or the bending of RF energy—if not accounted for, can severely impact the performance of naval radar and communication systems operating in the MABL. These impacts influence operations, acquisition engineering, and prototype RF system testing. By combining modern numerical weather prediction models with RF system models, it is possible to create site- and time-specific littoral RF system performance forecasts. The current technology is qualitative but has been used NSWCDD to support RF acquisition engineers, prototype RF system test engineers, and operational decision-makers. A strong research effort at NSWCDD aims to make significant increases in littoral RF system performance forecast accuracy in the next 5 years. This same NWP technology is being employed by NSWCDD to provide chemical agent transport and dispersion forecasts, and sound propagation forecasts. Each of these forecasting capabilities will help to ensure that warfighters are armed with effective capabilities and accurate information necessary to fight and win in the electromagnetic environment.

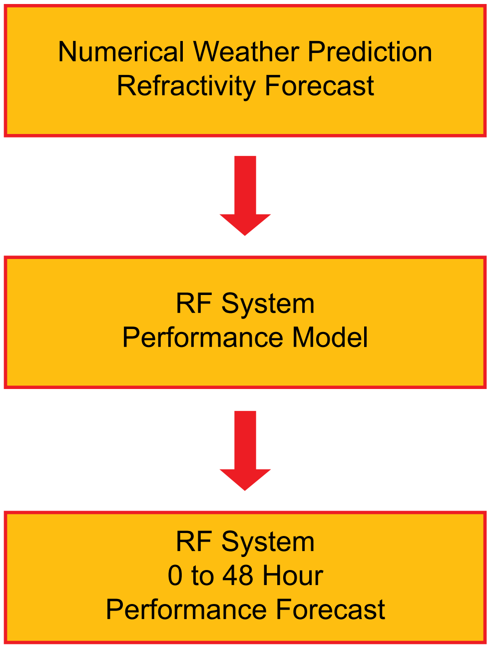


Figure 4. A Radar Performance Forecast Structure

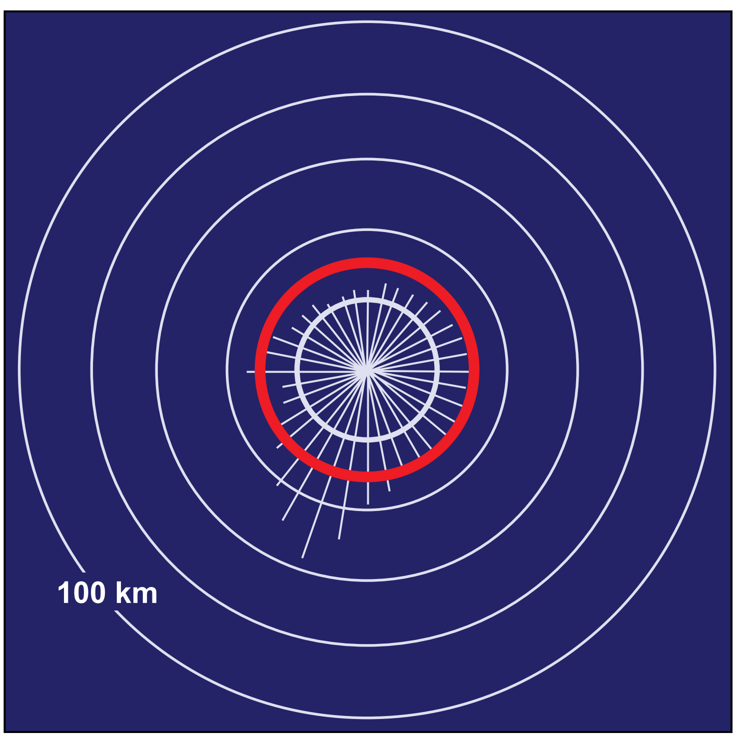


Figure 5. COAMPS/AREPS Model of the Detection Range of a Notional Target 10 m Above the Surface by a Notional S-Band Radar: Range rings are drawn every 20 km. The red ring indicates the detection range in a standard atmosphere.

Infrared Sensor and Image Processing for the Chemical Agent Plume Tracking Capability

By Dean Zabel

Chemical agents, when dispersed into the air, form plumes or clouds of particles that can impact warfighters and others in the immediate vicinity. Moreover, just as clouds in the sky form, move and dissipate, so do chemical agent plumes. Unlike clouds in the sky, however, chemical agent plumes might not be easily visible or detectable. Thus, warfighters could be exposed to chemical agents without knowing it, thereby endangering their lives and missions. Consequently, a means to test the capabilities of developmental chemical agent detection systems was needed to ensure that those systems provide the promised protection when deployed. The Chemical Agent Plume Tracking Capability (CAPTC), developed at the Naval Surface Warfare Center (NSWC) Dahlgren, provided a way to track chemical agent plumes to provide that testing capability.

CAPTC was designed to provide a referee capability for testing chemical-agent detection systems. A refereed capability refers to an unbiased measurement of the presence of a chemical-agent plume against which to compare the performance of the system under test. As such, the CAPTC operator will know at the start of a test which chemical is present in the plume. This permits the operator to configure CAPTC optimally for a particular simulant chemical agent release. The visual display provided by CAPTC also serves as a tool to assist the test director in conducting system tests. CAPTC employs near real-time tracking of chemical agent plumes using infrared (IR) images of the plume's location and extent, as determined from two or three locations.

Previous IR Camera Testing

Earlier testing using IR cameras was performed with the Joint Service Lightweight Standoff Chemical Agent Detector (JSLSCAD). Those tests demonstrated the need for very sensitive long-wave infrared (LWIR) cameras to provide near real-time plume tracking.[1] During those tests, it was found that the vapor plumes of a chemical agent simulant provided a low contrast to the ambient scene. This then required a significant amount of posttest processing time to make the plumes detectable. In order to provide near real-time imagery, very high-speed processing of the IR video was found to be required. This article overviews CAPTC, its IR camera requirements, and the software integration and architecture needed to make the system work.

The IR Camera Problem

The testing of chemical agent plumes must be carried out using simulants since actual chemical agents cannot be used. Because of their nature, the simulant plumes of interest to CAPTC are difficult to detect with an IR camera. The simulant is entrained as an aerosol in a high-velocity, high-volume flow of ambient air. Thus, the aerosol plume has very little temperature difference from the surrounding air into which it is injected. The mission of the chemical agent detector is to detect low concentrations of chemical agents. Thus, the content of the plume is not greatly different from the surrounding air mass against which it is to be detected. The requirement to be able to track the simulant plumes in near real time makes the problem even harder.

The IR cameras used for the JSLSCAD tests were wideband microbolometers. Microbolometers generally have detection bands from about 7.5 μ to 13.5 μ. This band more than covers the spectral characteristics of the simulants used in the JSLSCAD testing. However, microbolometers are not particularly sensitive. The microbolometers used for the JSLSCAD tests had minimum resolvable temperature differences (MRTD) of about 0.1°K. When viewed live, subtle changes in the IR scene caused by the vapor plume could sometimes be detected by the camera operator, but not always.

The posttest image processing for JSLSCAD tests used frame averaging. Up to 15 video frames were averaged to enhance the plume sufficiently to ascertain its position and size. This process was very labor intensive and time-consuming. The IR video collected for JSLSCAD tests was at a low frame rate of 5 frames per second. This meant that frame-to-frame registration was difficult to accomplish because both the camera and the plume generator were moving. This low frame rate was selected to manage the storage requirements for the digital video data. In retrospect, it would have been better to record the camera's maximum 60 frames per second digital video. An even higher frame would ease the frame-to-frame registration process. This became one of the factors driving selection of IR cameras for use in CAPTC.

Camera sensitivity becomes a limiting factor in how fast a frame rate may be utilized to collect enough photons to have a viewable image. As stated above, microbolometer technology is not very sensitive. To gain sensitivity, one needs to go to IR cameras that have cryogenically cooled detector arrays. Cooling the array and its associated readout electronics greatly reduces the sensor's noise by decreasing random electron motion. Commercial cooled cameras have achieved MRTDs in the 0.025°K range. However, most cooled LWIR cameras do not have the full detection-band capability needed to detect the simulants of interest. One of the simulants, sulfur hexafluoride, has a single spectral feature at about 10.6 μ. Thus, a camera detection band out to at least 11 μ is required.

Cooled LWIR cameras tend to have detector arrays of two types: quantum well infrared photodetector (QWIP) and detector arrays made from mercury cadmium telluride (MCT). Both types can be very sensitive. QWIP cameras have spectral detection bands of about 7.7 μ to 9.2 μ. Most MCT cameras have a similar detection band, though MCT can be formulated for wider detection bands. Unfortunately, few typical applications require the wider detection band, making the wider band MCT arrays much more expensive.

Spectral filtering also helps when the object to be detected exhibits emissive or absorptive spectral characteristics that are much narrower than the spectral response of the detector. Filtering helps by limiting the background to the spectral region of the object to be detected. The three simulants typically used in testing have different spectral characteristics such that a different filter would be optimum for each. This made it desirable to get a camera with an integrated filter wheel capable of holding at least four filters. The integrated filter wheel makes it possible to quickly select the optimum filter, or no filter at all, since CAPTC needs only three for each particular test run. The use of spectral filtering also drove the need for high camera sensitivity due to an increase in loss from the additional optical element.

The Camera Solution

An extensive search was performed to identify a commercially available IR camera to meet the needs of CAPTC. One MCT camera was located that had a detection band from 7.7 μ to 11.6 μ and included an integrated four-hole filter wheel. This was the CDIP Jade VLWIR. The Army's West Desert Test Center at the Dugway Proving Ground, Utah, had also selected this camera for a similar application. Between the time of selection and time of purchase, the Jade VLWIR was updated to the Titanium SC7900.

The Titanium is a very sensitive camera, with an MRTD < 0.025°K using a 320 horizontal × 256 (240 displayed) vertical MCT array. It supports a frame rate of 90 frames per second for full frames, with on-the-fly selection of any of its four filter wheel holes. The control and video output interface is gigabit Ethernet. The Ethernet interface is an improvement over the older RS-422 for digital video plus RS-232 for control used by the Jade. A software development kit was purchased with the camera to allow development of a control interface optimized for CAPTC.

The spectral characteristics of each of the three simulants were used to determine an optimum filter to use for each simulant. The specifications of the filters were: 7.75 μ to 9.25 μ, 8.6 μ to 10.6 μ, and 9.9 μ to 11.3 μ ±1% for each value.

The final piece of the IR camera is the optics. The JSLSCAD testing involved sensor-to-plume ranges of from 500 m to 6 km. The variation in ranges was needed to assess the sensitivity of the chemical agent detection system under test. Sometimes a plume release close (1.5 km) to the test system would be followed by one a long distance (5.5 km) away from the test system. Keeping the plume in the field of view and yet having sufficient resolution for the needed detail over this span of ranges dictated the use of multifocal optics. Quick physical access to the camera system would not be possible because the camera system needed to be environmentally protected from weather and RF emissions. Focusing and changing from near optics to far optics had to be accomplished quickly, so the optics needed to be remotely controllable. An appropriate commercial off-the-shelf multifocal lens had already been interfaced with the Titanium camera. The lens from StingRay Optics had triple field-of-view optics. It was fully controllable using a control box and 50-ft cable that came with the lens. The focal lengths were 75/150/300 mm, providing fields of view with the Titanium of 7.3° x 5.5°/3.7° x 2.8°/1.8° x 1.4°, respectively. The Titanium camera integrated with the triple field-of-view lens is shown in Figure 1 with the mounting plate portion of its environmental enclosure.

Figure 2 depicts a sample of images acquired by the Titanium camera. Shown are emissions from one of the Morgantown power plant stacks in Maryland at a distance of approximately 2.5 nmi. The first image is a basic IR image. The second image utilized some of the image-processing capabilities of the Altair software purchased with the Titanium camera. The Altair software package provided the ability for a frame-to-frame differencing view, which was done by subtracting one camera frame from the next. The resulting image showed only what changed between the two frames. The Altair software provided great posttest analysis capabilities when supplemented by software developed at NSWC.

Test Environment and Basic Data Capture Architecture

The software developed at NSWC provided the integration of a number of test assets, ships, or platforms with data-collection equipment, and the equipment aboard each asset to facilitate the test data collection of a given test event. CAPTC, as a system, encompasses the data-collection equipment on all of the assets tied together by the software. A notional test situation that would

Figure 1. Titanium Camera with the Stingray Optics on the Mounting Plate Part of Its Environmental Enclosure

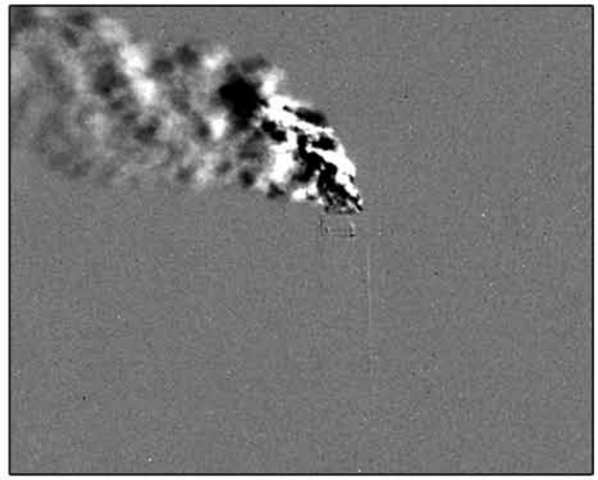


Figure 2. Sample Infrared Images Acquired by Titanium Camera

utilize the CAPTC environment is depicted in Figure 3. Each test asset is installed with test data-capture equipment that stores all local data and data broadcast from other assets. As a simulant is dispersed by the *Gatlin*, a Naval Surface Warfare Center, Dahlgren Division (NSWCDD)-owned ship outfitted with a blower system is used to generate the simulant plume, the data-capture equipment tracks and records the location of each asset and the calculated position of the chemical simulant plume. The basic equipment and data capture environment is shown in Figure 4. Figure 5 is a photograph of the *Gatlin* pierside preparing for JSLSCAD testing.

Each test asset or ship utilizes a local Global Positioning System (GPS) to track its current location and transmits this information over the low-data-rate (LDR) communications link. The LDR link is an omnidirectional link and provides for system commands and asset tracking information to be transferred to the main processing unit or the command console. The asset tracking information is crucial to the environment, as it is necessary to reposition or reorient the directional high-data-rate (HDR) link antennas. The HDR link is utilized to transfer the IR and situational awareness (SA) video to the command console.

A depiction of the command console Graphical User Interface (GUI) incorporating IR imagery, modeling and simulation (M&S) output, SA video, and position heading data from each of the platforms in the test is shown in Figure 6. The operator has multiple data windows that can track the multiple test assets of the CAPTC environment. The user interface is separated into upper and lower viewing areas. The lower display area provides a quick look at the status of each asset (i.e., latitude, longitude, and course) and the status of each CAPTC processing component executing on that platform. The upper display area provides the user with the ability to toggle through various options

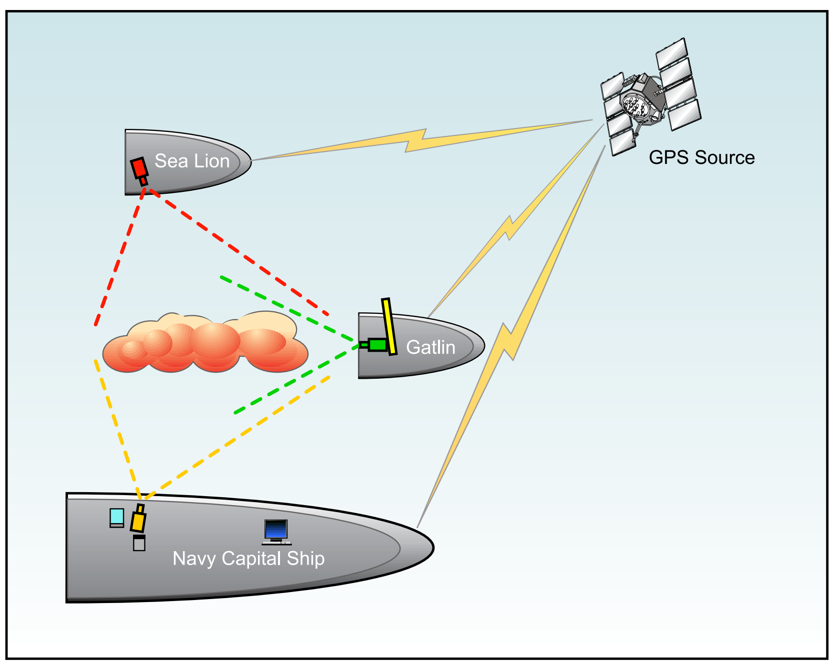


Figure 3. Notional CAPTC Test Environment

to view the IR video, the situation awareness video, the predicted weather information, and the status of the simulant plume dispersal.

In addition to the GUI, test event data is sent to a simulation display window that tracks and displays each test asset and the simulant plume in a 3-D display environment using the Simulation Display (SIMDIS) application developed by the Naval Research Laboratory (NRL). As each test asset sends its positional data (latitude and longitude) to the command console, the console sends the information to the SIMDIS for rendering.

Conclusion

The CAPTC mission presented some complex technical challenges. In solving those challenges, an IR camera with appropriate capabilities, filters, and optics was found that—when coupled with the software and architecture developed by engineers at NSWC Dahlgren—enabled the detection and tracking of difficult-to-see simulated chemical agent plumes. Moreover, a data acquisition system was designed and assembled by NSWC engineers that handled the significant image processing requirements. A user interface was developed that was capable of meeting the rigors of the refereed testing environment. A user interface was developed that was capable of meeting the rigors of the refereed testing environment. The system was successfully demonstrated during the month of July 2009. The CAPTC system provides a unique, new capability to the testing community that will ensure fielded chemical agent detection systems will help protect warfighters by alerting them to chemical agent plumes that might otherwise go undetected.

Acknowledgments

James Tharp (iO Technologies, Inc.) and Gloria Vaquer (NSWCDD) contributed to this article.

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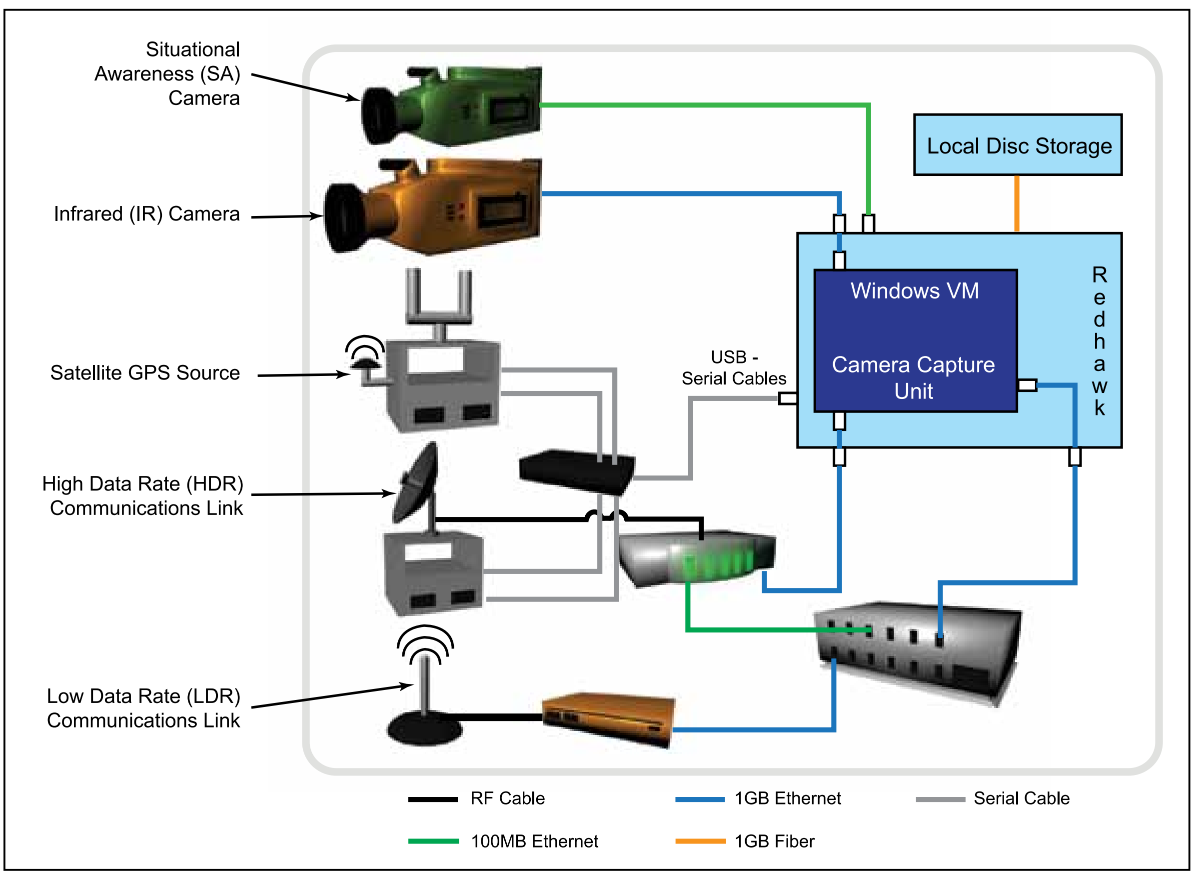


Figure 4. Basic Data-Capture Architecture

Figure 5. *Gatlin* Simulant Plume Dispersal Boat Preparing for JSLSCAD Testing in Summer 2004

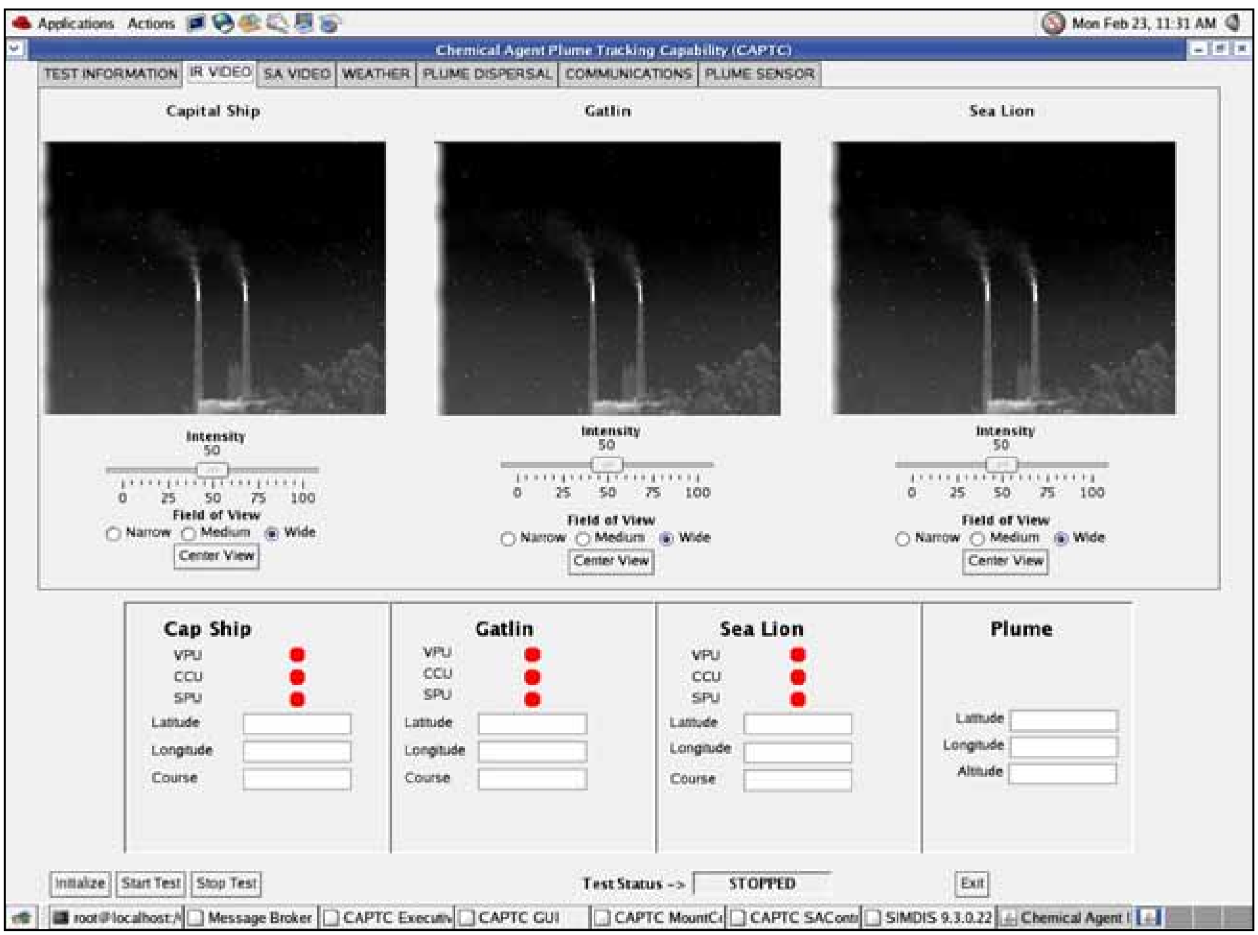
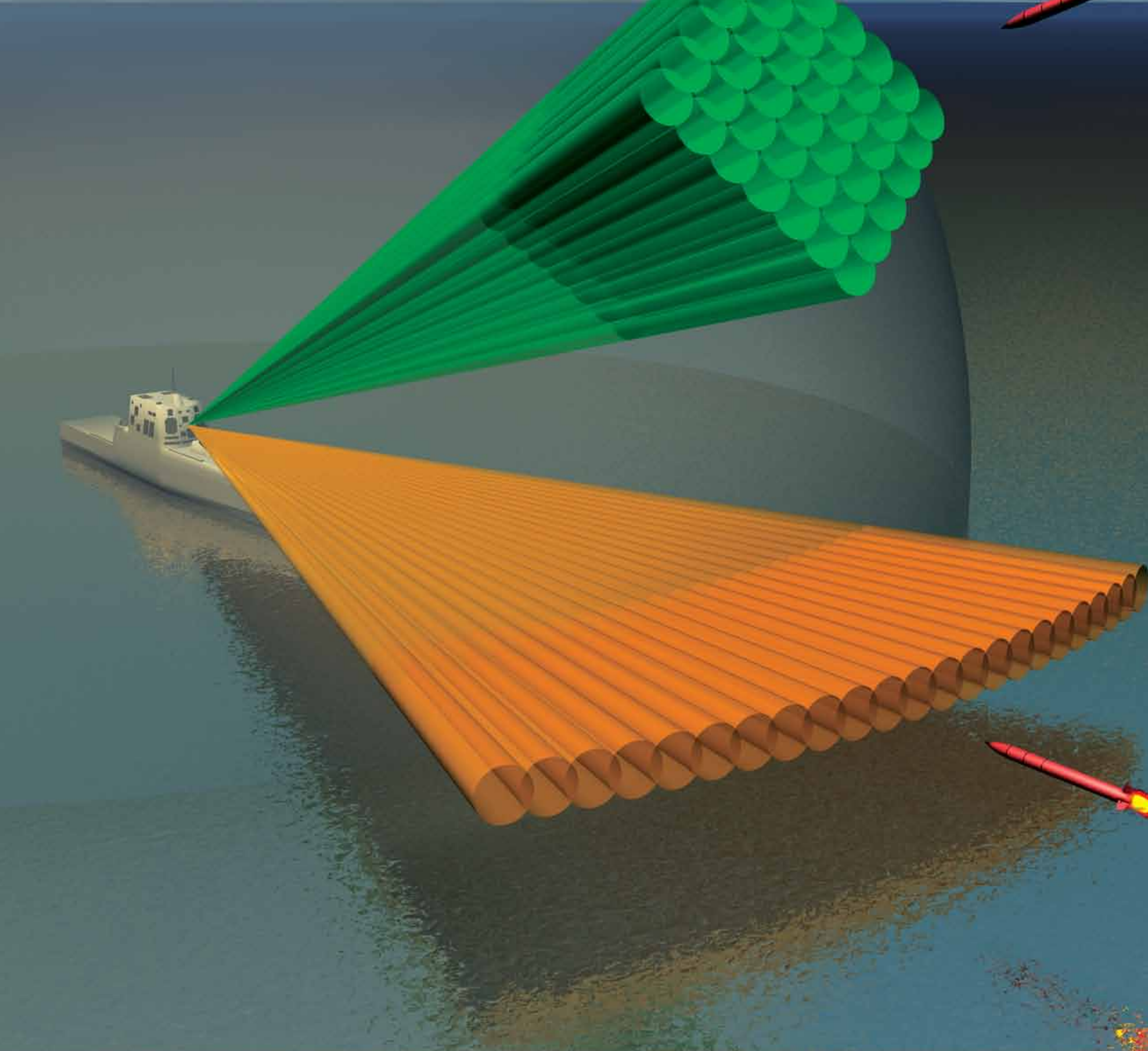
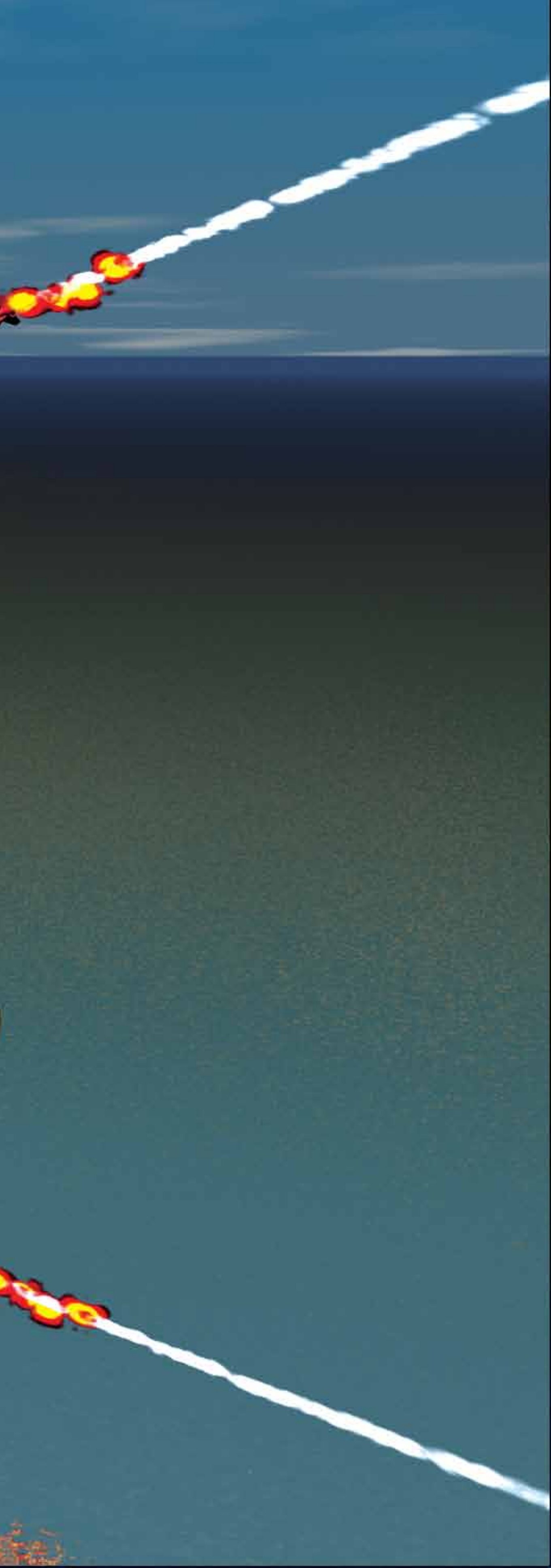


Figure 6. Sample CAPTC Command Console GUI

Digital Array Radar Test Bed

By Ronnie A. Stapleton and Carlos G. Tua





Digital Array Radar Test Bed

The Theater Air and Missile Defense (TAMD) radar systems envisioned for use in next-generation naval surface combatants are anticipated to include high-power apertures operating at S-band. While the high power of these systems is driven by ballistic missile defense requirements, the radars are, by necessity, multifunction and will also be required to detect and track targets at low elevations in clutter. This poses a problem, as the instantaneous dynamic range required of the system to support operation in clutter is not easily met with traditional receiver-exciter architectures built with conventional components. Additionally, the high power and narrow beams required for missile defense functions results in a system that is unable to search the requisite volume of space in a reasonable time frame.

To mitigate these issues, radar system architecture has been developed that uses multiple receiver-exciter subsystems operating in parallel in a distributed fashion. This results in a system with increased dynamic range and stability, as well as the ability to search with clusters of beams to increase the system volume search update rate.

This article provides an overview of the Digital Array Radar (DAR) Project, sponsored by the Office of Naval Research (ONR) (Code 313) that is performing risk reduction for next-generation TAMD S-band radars and on a test-bed system that is being constructed to validate system calibration and calibration maintenance. The DAR concept is depicted in Figure 1.

The DAR effort concentrates on developing an open, modular system architecture that applies to the entire radar system, including the development and demonstration of subsystem technologies in the areas of receiver-exciters, digital beamforming and signal processing. A significant attribute of this

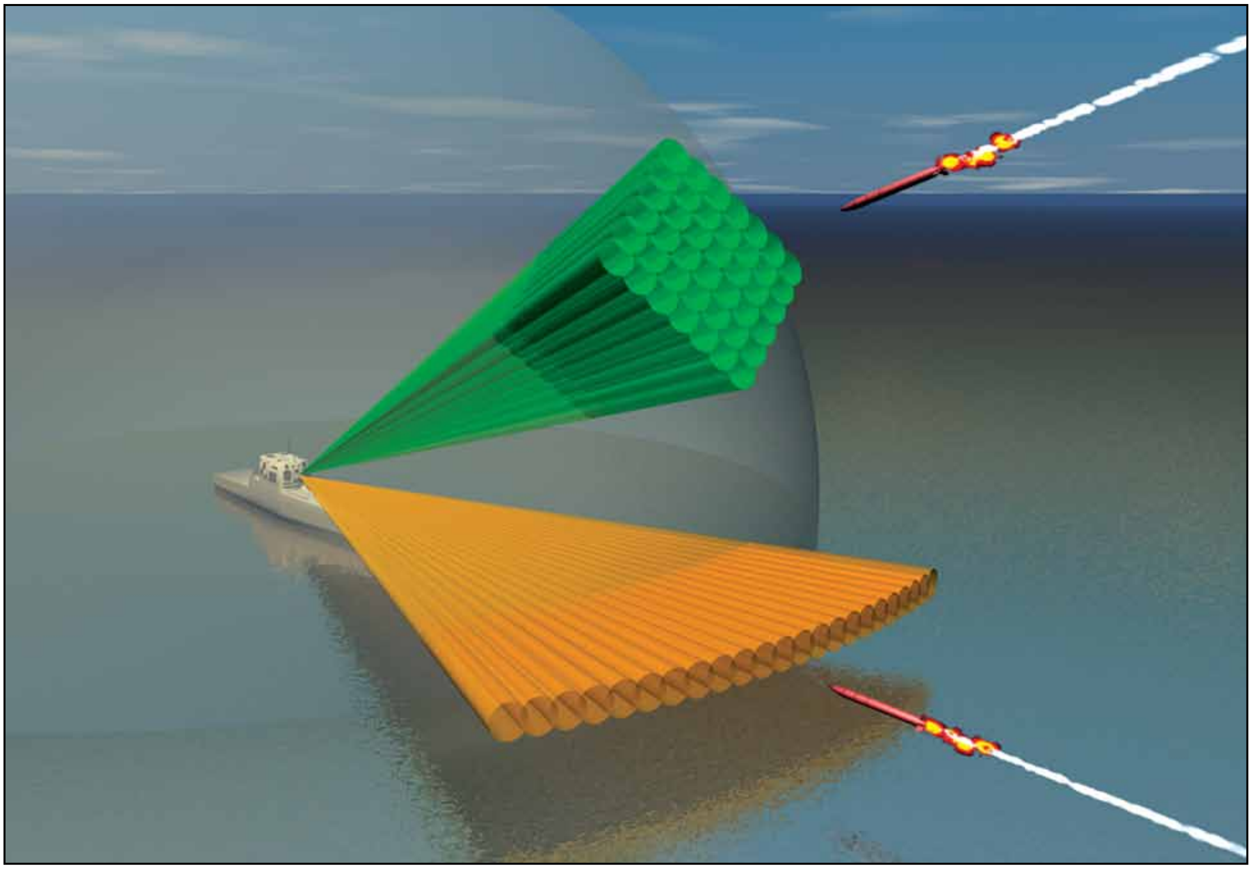


Figure 1. DAR Open-Architecture Concept That Enables Multiple Simultaneous Beams and Multifunction Capabilities

architecture is the use of an interface control document that specifies the messages used among all subsystem elements. A second significant attribute of the design is that all system and subsystem control is affected with commands based on time of day, resulting in only two interfaces—one for control messages and one for time—entering each subsystem. These two elements allow subsystems to be modular in design, which in theory, allow subsystems from multiple vendors to be used to create the overall system. To date, the following participants have collaborated on various elements of the DAR system development:

- ONR
- Naval Surface Warfare Center, Dahlgren Division (NSWCDD)
- U.S. Naval Research Laboratory (NRL)
- General Dynamics Advanced Information Systems
- Lockheed Martin Government Electronic Systems
- ITT Corporation
- REMEC Defense and Space

The DAR program has progressed to the point where end-to-end radar is required to effectively test the radar subsystems. To this end, a test bed is being constructed that will serve as an instrumentation radar with enough functionality to retire risk through engineering tests while demonstrating radar functionality representative of that required in a tactical system. Figure 2 shows the DAR Open-Architecture Block Diagram. Construction of this test-bed radar is being accomplished by integrating all of the elements behind the antenna, which have been the focus of the DAR program, along with a surrogate array antenna and associated electronics. The test bed will implement the five subsystems marked in blue, while the gray Combat and Navigation System blocks are part of a tactical system and, as such, will not be implemented in the prototype.

Although the focus of the DAR program has been on developing the radar subsystems behind the antenna, the additional requirement to build a prototype radar system necessitated an antenna and the associated active-array electronics. In lieu

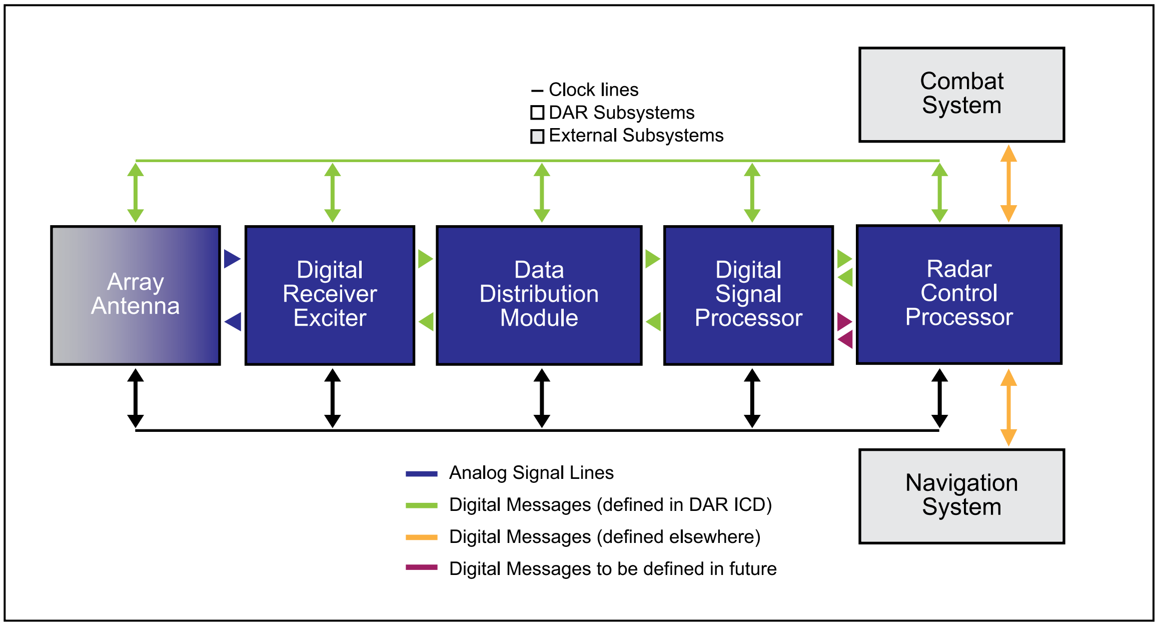


Figure 2. DAR Open-Architecture Block Diagram

of designing a traditional active array with a large number of elements, the DAR program is using a novel pillbox horn antenna array that offers a combination of high gain, low loss, and simple fabrication.[1] This antenna, designed by NRL, has been proven with a four-element prototype and is now being constructed with a 64-element design that will be used in the risk-reduction test-bed radar system. The DAR Test-Bed Antenna Array is depicted in Figure 3.

In order to avoid the development cost associated with a conventional active-array, transmit-receive module, the DAR electronics associated with the antenna are built using individual power amplifiers to provide higher power signals on ***transmit*** and individual low-noise amplifiers to provide low-level signal amplification on ***receive***. They are mounted on a cold plate for thermal management. A prototype can be seen in Figure 4.

The digital receiver exciters used in the system are responsible for conversion of digital data to S-band signals on transmittal and for conversion of S-band received signals to digital data on reception. The data distribution module accepts data from the receiver over an industry standard 10-gigabit Ethernet interface and performs all of the complex mathematical digital beamforming computations in real time required to produce antenna beams. The system signal and control processing functions are implemented in real time with a commercial blade server computer system from IBM. Figure 5 shows each of the subsystem components that will be used to construct the test-bed radar system.

All portions of the test-bed radar system, except for the antenna, were available for testing at the General Dynamics Advanced Information Systems facility in late 2008. In order to facilitate early integration, a microwave-fiber optic delay line and Doppler repeater were used, along with a modest amount of custom-engineered microwave hardware to allow early integration and testing of most of the subsystem elements in a laboratory environment. Figure 6 shows a photo of the microwave-fiber optic delay line and Doppler repeater.

Successful integration, calibration, and testing of the elements in this fashion will greatly accelerate the transition of the radar to a functioning test bed radiating in free space. The test bed is currently

(a) (b)

Figure 3. DAR Test-Bed Antenna Array: (a) Antenna has been assembled inside a steel frame for rigidity, and (b) Outline of horn and parabolic reflector have been constructed out of aluminum standoffs.

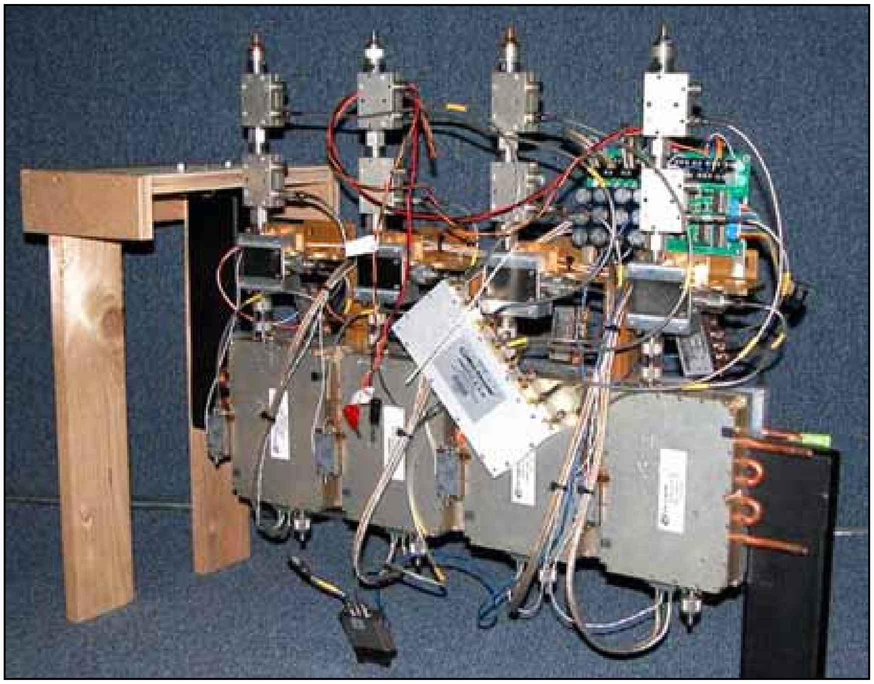


Figure 4. Power Amplifiers, Low-Noise Amplifiers, and Supporting Microwave Hardware and Electronics Mounted on a Cold Plate

DREX

Data Distribution Module

Digital Signal Processor and Radar Control Processor (IBM Blade Servers)

1- and 10-Gigabit Ethernet Network Switch

Figure 5. DAR Test-Bed Subsystems

(a)

(b)

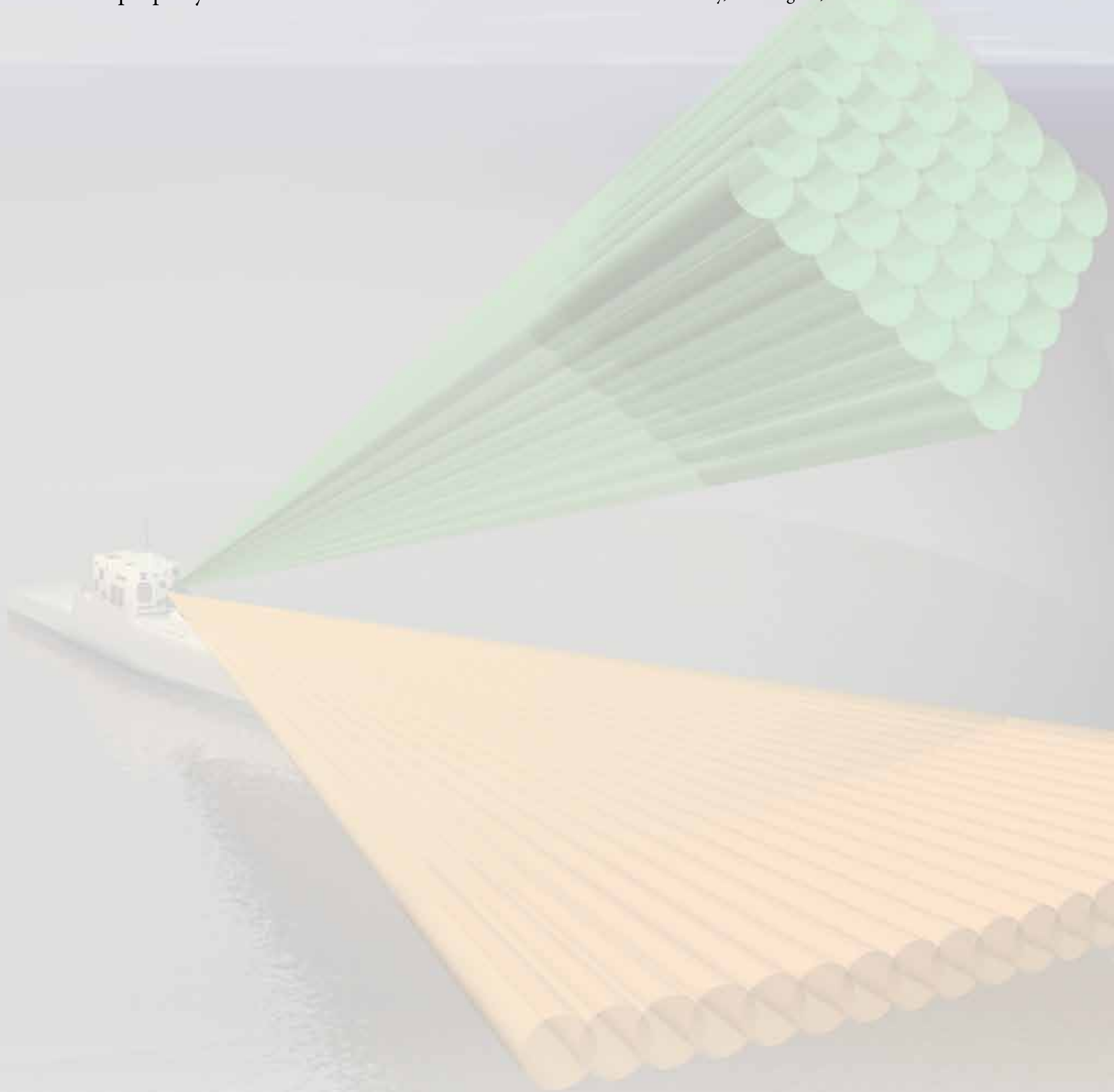
Figure 6. (a) Microwave Hardware and Microwave-Fiber Delay Line; (b) Doppler Repeater

being assembled at NSWCDD's Search and Track Sensor Test Site overlooking the Potomac River. The first phase of the DAR test bed will be based on a four-element design with rather modest capabilities. Throughout 2009 and continuing into 2010, the system will grow to 32 and then 64 channels through the addition of a larger antenna, combined with additional receiver-exciter units and processing subsystems. Activities during this time will focus on calibration and calibration maintenance of the transmit and receive subsystems, which is critical to achieving high-quality antenna patterns and rejection of system clutter.

To date, all development on the DAR program has been accomplished without any contractor-specific intellectual property associated with the architecture and subsystem interfaces. The test bed that is being built will serve as a tool both to highlight the subsystem capabilities to enable transition into a tactical system, but also as a tool for experimentation in areas that can be used to benefit the radar community. Lessons learned from all tests will be shared with both government and industry so that next-generation systems can be successfully designed, built, and ultimately, fielded in the hands of warfighters in order to increase the capabilities of radars to perform their missions in the face of current and emergent threats.

Reference

1. W.R. Pickles and M.G. Parent, *Pillbox Antenna with a Dipole Feed*, U.S. Naval Research Laboratory, Washington, DC.



Draft – Working Papers

Multifunction Electronic Warfare (MFEW) Technology Development Program

By Janine Knott

Figure 1. An artist rendering of the *Zumwalt*-class destroyer DDG 1000, a new class of multimission U.S. Navy surface combatant ship designed to operate as part of a joint maritime fleet, assisting Marine strike forces ashore, as well as performing littoral, air, and subsurface warfare. (U.S. Navy photo illustration/Released 080723-N-0000X-001)

The Multifunction Electronic Warfare/Electronic Support (MFEW) Program evolved from the Office of Naval Research (ONR) Advanced Multifunction Radio Frequency (RF) Concept, Future Naval Capabilities. In support of this initiative, a single Advanced Development Model (ADM) contract was awarded to design electronic support functionality per the DDG 1000 Electronic Warfare (EW) specification as a modular, open, scalable system to support capability growth and application across the entire fleet. The Electronic Warfare and EOIR Systems Branch at the Naval Surface Warfare Center, Dahlgren Division (NSWCDD) provided key support as the MFEW System Engineering lead to the Naval Research Laboratory and the prime contractor, Northrop Grumman Baltimore, in the areas of design, requirements assessment, risk assessment, and test and evaluation planning. The 2-year ADM project included the detailed design and ADM build and test, followed by a transition to Naval Sea Systems Command (NAVSEA) in 2008 via the technology transition agreement between ONR and NAVSEA.

Program Goal

The goal of the MFEW Program was to develop a MFEW ADM for the DDG-1000 ship class that demonstrated key electronic surveillance capabilities, including high probability of intercept, precision direction finding, and specific emitter identification. The plan was to conduct MFEW ADM testing that satisfied technology development phase requirements to enable a smooth transition to the system development and demonstrations acquisition phase. The MFEW ADM was leveraged as an opportunity to resolve significant cost, schedule, and performance risks early in the acquisition process. This was accomplished by using modified Surface Electronic Warfare Improvement Program (SEWIP) electronic support equipment to ease backfit integration. The ADM design mitigated critical technical risks, refined requirements, and also permitted experimentation and trade studies that addressed technical system design and development program challenges. Key technical challenges included co-site interference and multipath interference. The program used a modular, scalable, and open architecture capable of supporting additional EW functionality and platform configurations including backfit. The flexibility to handle new threats, the ability to add capability, and the ability to adapt to a ship's radio frequency interference/electromagnetic interference (RFI/EMI) environment were also included in the design. An image of the DDG 1000 is shown in Figure 1 (see title page).

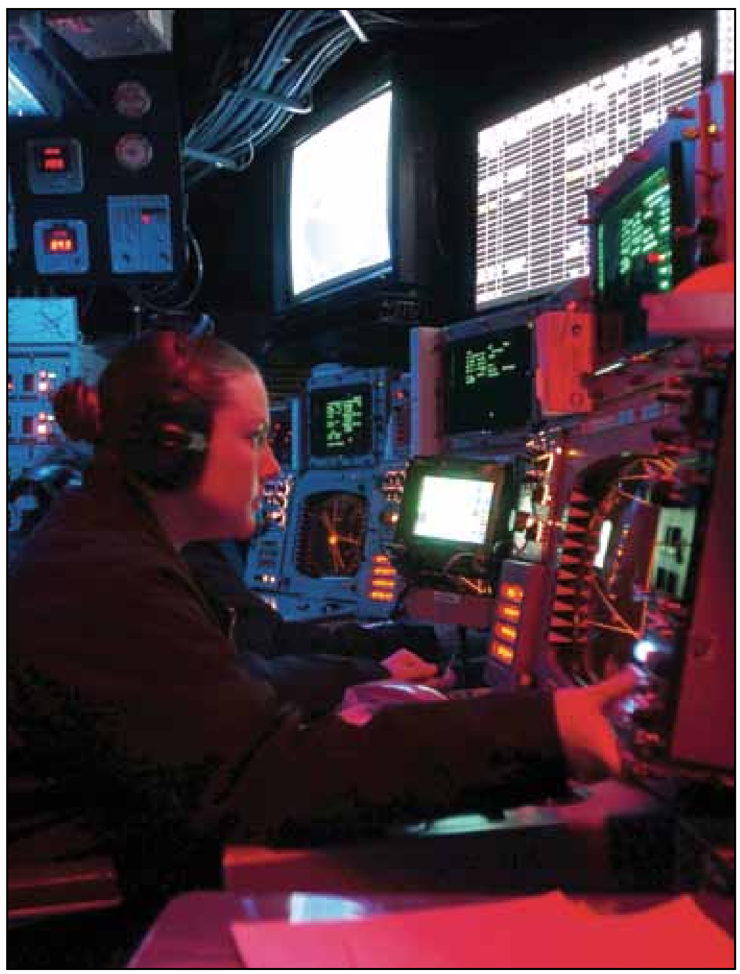
System Architecture and Design

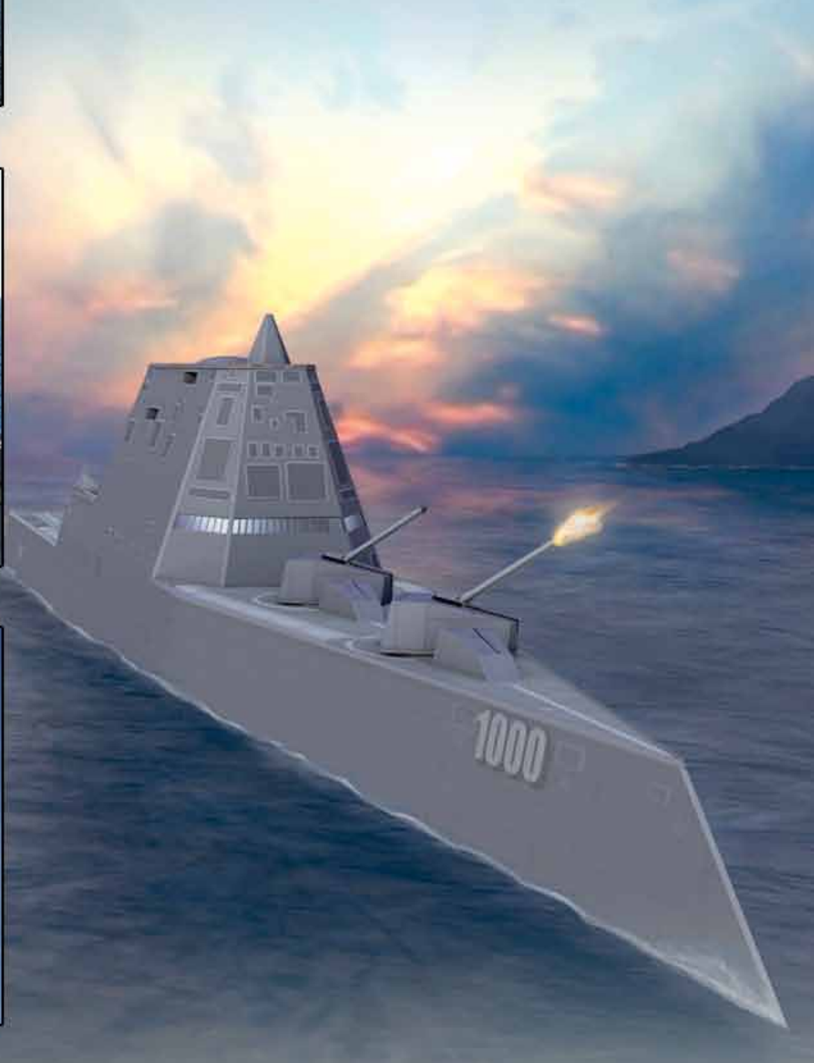
The MFEW ADM consisted of a single-quadrant linear interferometer with a high probability of intercept and precision direction-finding capabilities, as well as a series of digital receivers and advanced pulse processing that provides antiship cruise missile detection and situational awareness in the presence of strong interference and dense emitter environments. As mentioned previously, the principal design objectives of the MFEW program were to reduce technical, cost, and schedule risk for the development and production of a next-generation ship's EW system. To accomplish this, the team worked with Navy operators to refine EW requirements and to develop the EW concept of operations, threat characteristics, and scenarios. The RFI/EMI environment and ship signature requirements of the DDG-1000 class were significantly different than in previous ship classes. The project was directed to employ Modular Open Systems Approach (MOSA) principles to provide a total fleet solution and to simplify future technology insertions. The design was to also provide for growth to a multifunction system, potentially including high-gain, high-sensing systems; electronic attack capabilities; frequency extension; and electro-optic and infrared (EOIR) systems and paths to add communications and radar functions. The project leveraged systems engineering, software, and hardware developed on the SLQ-32, the Advanced Integrated Electronic Warfare System (AIEWS); the SEWIP; and the EA-6B and EA-18G programs. It also used existing EW processing from SEWIP and an overwater, direction-finding solution proven in the AIEWS.

The MFEW system was further designed to use a wide variety of antenna/aperture types as required by the ship configuration and functional capability and employs a wideband, distributed radio frequency (RF)-to-intermediate frequency (IF) converter with multiple RFI mitigation features. Moreover, MFEW uses a common digital receiver/exciter building block that supports acquisition; direction finding; modulation on pulse; low probability of intercept waveforms; built-in-test/calibration; and electronic attack. Additionally, MFEW employs open, industry standards at all single replaceable unit (SRU) interfaces. Commercial off-the-shelf (COTS) hardware and open software are used for all pulse, emitter, and related processing.

The schedule for the MFEW project was very aggressive. It began with a kickoff in October 2005, followed very quickly with a system design review in December 2005, a preliminary design review in March 2006, and a critical design review in June 2006. Factory acceptance testing began in December 2006 with integration of the system at NRL's Chesapeake Beach Test Bed in late Summer 2007 and demonstration in December 2007. The compact 2-year schedule allowed for a ship demonstration during the Rim of the Pacific Exercise (RIMPAC) in the summer of 2008. The final report, dated August 2009, and analysis data is available from the Naval Research Laboratory Radar Division.

In all, the MFEW Program met its goals to develop a MFEW ADM for the DDG-1000 ship class that demonstrated key electronic surveillance capabilities of high probability of intercept, precision direction finding, and specific emitter identification. These results will help ensure that future Navy ship classes and warfighters will have enhanced EW capabilities necessary to identify and defeat adversary capabilities.

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Innovation Strategies for Undersea Sensing

By Tom Choinski

Five years ago, the Sensors and Sonar Systems Department of the Naval Undersea Warfare Center (NUWC) set off on an organizational experiment. The department's experiment was the creation of a division consisting of over 60 scientists and engineers whose sole purpose was innovation. The organization was named the Emergent and Transformational Systems Division, and their mission was to address emerging fleet needs by developing and transitioning radically innovative technologies to the fleet. The technologies primarily focused on undersea sensing and undersea warfare.

Other divisions in the department and at NUWC also innovate. What made this division unique was that its innovation couldn't be incremental or along traditional product lines. The innovation had to be radical and game-changing. The focus was to work on concepts that could potentially change the calculus of undersea warfare from a sensing perspective. Insofar as the division is still improving and growing its ability to innovate, a lot can be learned from its experiences over the last 5 years.

Innovation is important because advancements of all kinds are taking place at a rapid pace due to globalization. Globalization enables everyone to have equal access to technology on a level playing field. Global leadership will be gained by those organizations that can transform their resources rapidly to meet emerging needs and requirements. The Navy has emphasized the importance of innovation through several organizations such as the Chief of Naval Operation's Strategic Studies Group (CNO SSG), the Naval Warfare Development Command (NWDC), the Office of Naval Research (ONR), and the Warfare Centers. The ability to transform resources rapidly has also been identified as a key capability for future success by organizations such as the Lawrence Livermore National Laboratory and the Central Intelligence Agency (CIA).

Warriors must have a need and the desire to adopt the concepts and technologies that are developed. The technologies must also fit within the context of existing doctrine, organization, training, materiel, leadership, personnel, and facilities (DOTMLPF) for success. In addition, new concepts must support requirements, operational concepts, and acquisition planning.

The Emergent and Transformational Systems Division achieved success in innovation through a strategy that encompassed education, invention, prototyping, at-sea experimentation, analysis, collaboration, innovation cells, and adoption by the warrior. Each of these components of the strategy is subsequently discussed.

Education

The division's education started with the Innovation Strategies Course offered through NUWC University. The course focused on the innovation equation:

Innovation = f(Invention, Commercialization, Diffusion)

People often confuse innovation with ideation or creativity. The course took as its premise that innovation is a function of invention, militarization, and the diffusion or the adoption of the idea by the warrior. Consequently, a great technological idea that is not adopted by the warrior would not qualify as an innovation under this definition. The course was a 1-day course developed from extensive research compiled by the author, as well as many people at NUWC who provided information from related experiences and research on the topic. The extensive bibliography for the course—which included articles, books, and videos—was donated to NUWC's Technical Library so that everyone at NUWC could benefit from this information. Figure 1 shows examples of new additions to NUWC's library resources on innovation.

Figure 1. NUWC Library Resources on Innovation

Invention

Invention leveraged the talented and experienced technical staff of the division. Many new products were invented, developed, and prototyped through support provided by NUWC's bid and proposal program; ONR; Naval Sea Systems Command (NAVSEA); and Program Executive Office, Naval Mine and Anti-Submarine Warfare Command (PEO-IWS5A). These organizations also supported work in the prototyping, experimentation, and analysis phases of innovation. Figures 2 through 5 show one idea conceived and developed under NUWC's bid and proposal program. The idea was based on undersea distributed networked sensing (UDNS) techniques using small or microsized unmanned surface vessels (USVs) that could be controlled, navigated, and tracked through Web-based tools. The micro USVs could be used to provide inexpensive, expendable, mobile undersea sensors for riverine applications or to investigate potential undersea targets at low cost. Figure 6 shows another device that provides a Web-based buoyant radio frequency (RF) location function that could be used to locate assets that need to be recovered after undersea experimentation.

Prototyping

Prototyping was critical to the development of new technology concepts. Existing systems tended to offer the best opportunities for prototypes because ideas could be developed quicker by modifying those systems. Moreover, modified systems had greater potential for transition into an acquisition pipeline and would be adopted by the warrior faster if the existing system was already proven and accepted by the fleet. Figure 7 shows nontraditional undersea warfare concept prototypes developed from standard mobile target devices called Expendable Mobile Anti-submarine Warfare Training Targets (EMATTs). These prototypes were designed, built, and used during at-sea experiments. Modifying existing systems enabled rapid prototyping and at-sea experimentation in an expeditious manner.

At-Sea Experimentation

At-sea experimentation by the fleet is essential to any technical innovation process. Experimentation enables the fleet to take new technology concepts and judge the values and merits of the technologies for themselves. Technology concepts that offer potential value to the fleet can be shaped and modified into a form that will be useful to the fleet in the future. In addition, at-sea experimentation enables the fleet to develop and mature doctrine and operational concepts, as well as tactics, techniques, and procedures for

Figure 2. UDNS Micro USV

Figure 3. UDNS Micro USV Compared to Spartan USV

Figure 4. Video Image for UDNS Micro USV

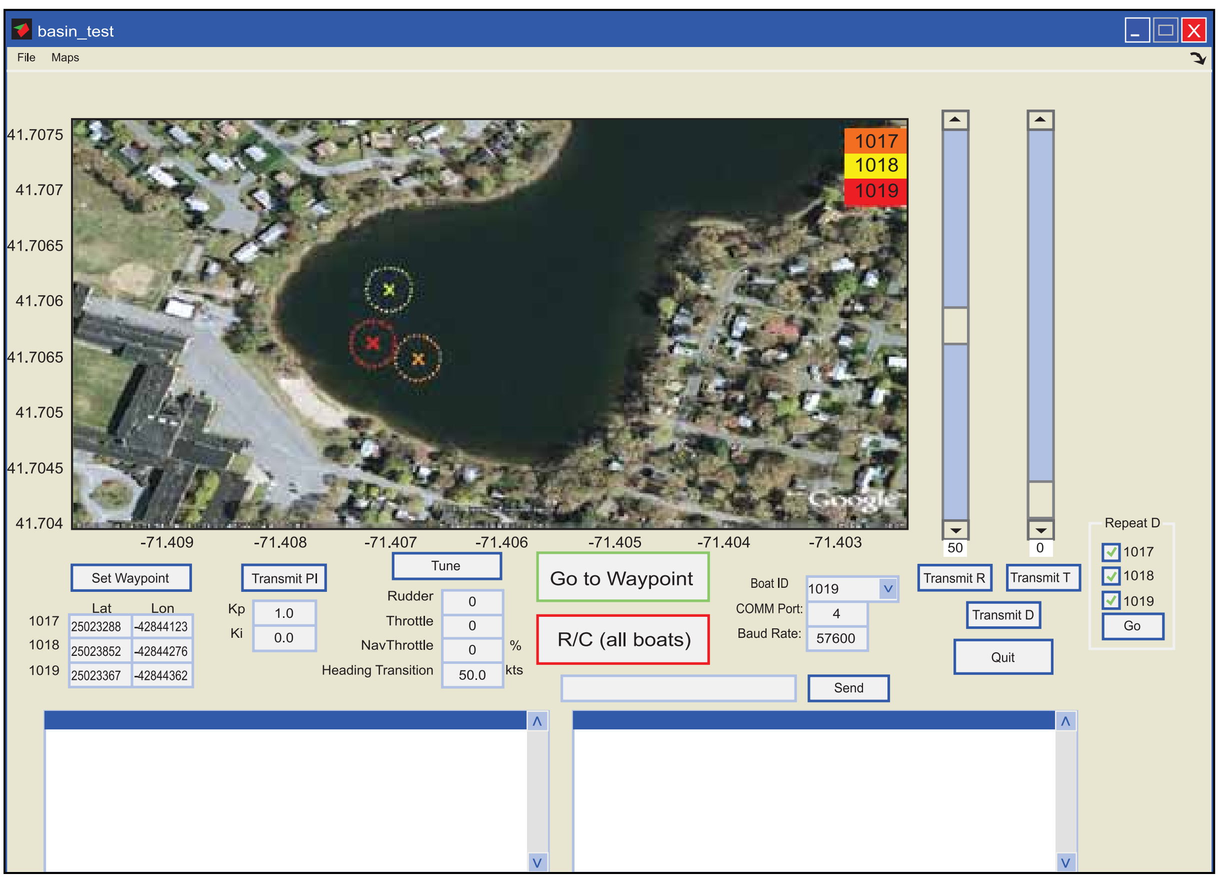


Figure 5. COTS Web-Based Control for UDNS Micro USV

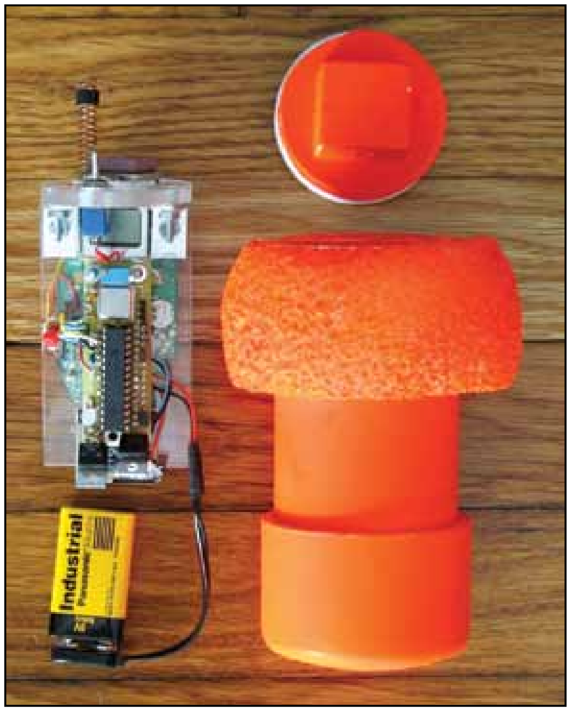


Figure 6. Web-Based Buoyant RF Locator for Experimentation

Figure 7. Nontraditional Undersea Warfare Prototypes for At-Sea Experimentation

new technology. Through experimentation, technology and fleet concepts are developed in parallel to expedite the innovation process. The engineers in the division participated in at-sea experimentation, often during adverse weather conditions, to collect the data necessary for assessment. Figure 8 shows one of the ships involved in experimentation during TASWEX-04. The experiment was conducted immediately following a typhoon.

Figure 8. Image of Waves Crashing on Deck of Ship During TASWEX-04 Immediately Following a Typhoon

Analysis

Analysis is critical throughout the invention, militarization, and diffusion phases of innovation. For acoustics, signal strength is one characteristic that is often analyzed for new concepts. Figure 9 shows the results from a preliminary target strength concept for an innovative, acoustic shadow project funded with internal NUWC resources. This concept leveraged background noise characteristics to enhance the detection and localization of underwater objects such as submarines. The analysis shown in Figure 9 demonstrates how the aspect dependencies could be assessed for target strength of a notional submarine. In addition to using modeling and simulation tools, the analysis also included operational assessments. Experience gained and relationships developed between scientists and engineers and the fleet from at-sea experimentation contributes to successful tactical and operational performance assessments of new concepts and technologies. Working with the fleet to determine the operational value of new technologies is important for the adoption and acceptance of innovative technologies.

Collaboration

Early fleet experimentation with developmental systems facilitates the adoption of innova-

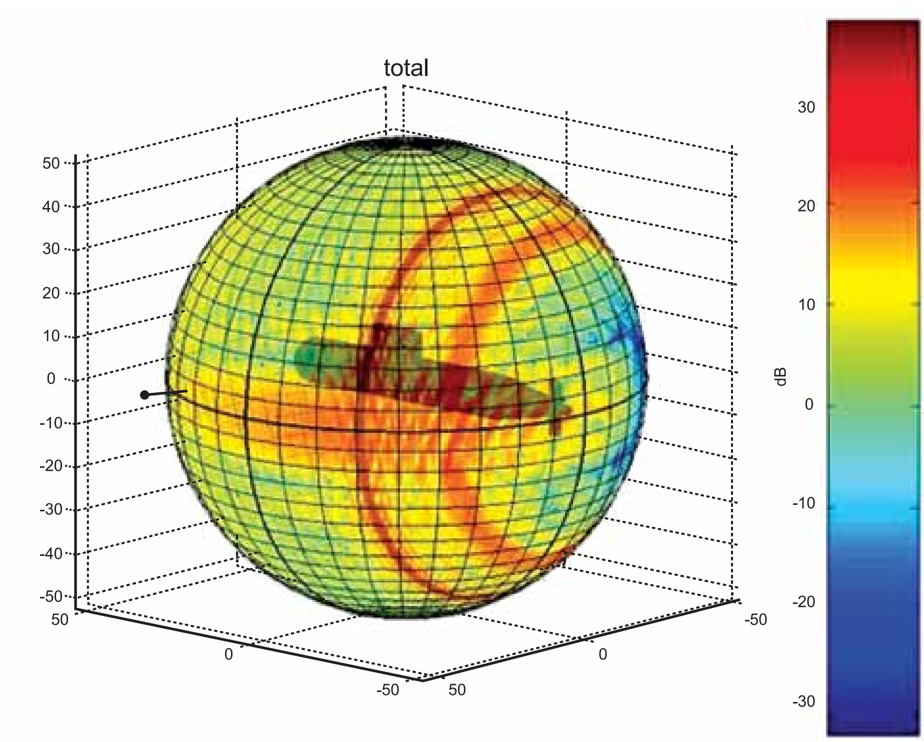


Figure 9. Target Strength Modeling for Acoustic Shadow

tive technologies through collaboration among the technology developers, the end users in the fleet, the acquisition community, and the engineers of the existing systems. It facilitates communication and sets the stage for observation by the end user (fleet operators, officers, and commanders) concerning the effectiveness, compatibility to tactics and fleet systems, reliability, and applicability to their operational requirements. At-sea experimentation of new technologies and concepts allows the fleet to make the final judgment and comparison of the performance of existing systems. Figure 10 illustrates recent examples of early fleet experimentation of undersea systems. The developmental systems were used along with existing fleet systems and as part of a typical integrated antisubmarine warfare (ASW) prosecution involving an ASW commander, a destroyer squadron, and ASW aircraft. The fleet was proactively involved in the tactical employment of the developmental system offering hands-on lessons learned.

Collaboration occurs throughout the innovation process, not just in experimentation. Practically all of the division's success stories involved collaboration with other organizations; some within NUWC, some within NAVSEA, others with the Department of Defense (DoD) (the services), industry, and international partnerships. The Naval Surface Warfare Center (NSWC) Carderock, NSWC Dahlgren, the Air Force, and The Technical Cooperation Program (TTCP) are a few examples of the collaborations that have been integral to the division's success. NUWC has collaborated with NSWC in several technology areas. The division leveraged RF radar expertise from NSWC Dahlgren, as well as tow-body design capabilities, test facilities, and marine architect and design expertise from NSWC Carderock. These collaborative initiatives reduced cost and development time while ensuring a higher quality product. Foreign collaboration was built through TTCP and through partnerships among Australia, Canada, New Zealand, Great Britain, and the United States.

Innovation Cells

Innovation cells are another venue where collaboration is important. They help to facilitate analysis. For example, one innovation cell focused on issues associated with at-sea experimentation and utilized the research on the diffusion of innovation. The results of the innovation cell shown in Table 1 illustrate how the 11 attributes of innovation were assessed.

A discussion on each of the 11 attributes is beyond the scope of this article, but note that the effort uncovered observability as the crucial attribute to the undersea experimentation process. Each of the 11 attributes of the diffusion of innovation was ranked on a scale from 1 to 7, where 1 indicated a favorable rating, and 7 indicated a poor rating. Reliability, radicalness, observability, and economic advantage received poor ratings. Reliability and economic advantage were rated poor not because of the performance of the system, but because of a lack of communication of the performance of the system to the fleet. By changing the way we communicated the reliability performance and economic advantage of this system, we were able to improve these ratings. The rating for radicalness could not be addressed because of the fundamental nature of this innovative concept.

However, the rating for observability uncovered a fundamental issue with new undersea sensing concepts. Observability is the degree to which the results of an innovation are communicated as being visible to others. The observability attribute offers unique challenges for the undersea sensing environment simply because there is very little visibility under the sea. Data is collected during undersea experiments and often requires months of analysis in the laboratory to assess performance. This is especially important because the participants from the experiment are often long dispersed by the time the analysis results are reported out in detail. The innovation cell identified ways to improve observability during undersea sensing experiments. These improvements included:

- Planning for Experimentation
  - Empower riders with a priori knowledge of scenarios
  - Plan to collect mission-based metrics
  - Disseminate experiment plan to appropriate players
  - Develop a communication plan before the experiment
- Communication During Experimentation
  - Leverage low-bandwidth chat
  - Improve platform tracking with the ASW Tactical Assessment System (ATAS)
  - Integrate overhead assets; e.g., Global Hawk
  - Use acoustic communications (ACOMMS) for in situ submarine communications
  - Use the submarine as the hub for analysis
- Analysis After Experimentation
  - Capture warrior observations via the Web
  - Conduct collaborative analyses
  - Disseminate results electronically to solicit feedback

Figure 10. Collaboration Through Experimentation

Table 1. Innovation Cell Results for Undersea Experimentation

Attribute	Intent or Perception (1–7)	Comment
Applicability	1	Highly applicable, high utility
Reliability	6	Not strongly communicated
Compatibility	1	Compatible with existing concepts of operation
Divisibility	2	Alternate options communicated
Radicalness (reverse coded)	5	Communicated effort as being different
Complexity (reverse coded)	2	Not highly complex (context dependent)
Trialability	1	Use of systems in experimentation strongly emphasized
Observability	4	Not strongly communicated
Effectiveness	2	Analysis used to determine performance
Commutuality	1	Complementary nature strongly articulated
Economic Advantage	5	Not strongly communicated
Total	30	
Avg	2.73	

Adoption

The diffusion of innovation, including adoption by the warrior, remains as one of the greatest challenges in the innovation process to date. Figure 11 provides a notional depiction of how the innovation and militarization pieces of the innovation equation have been expedited since the Cold War. The advent of commercial off-the-shelf (COTS) equipment and programs, like the Acoustic Rapid COTS Insertion (ARCI) Program, has made great strides in shrinking the invention and militarization phases drastically. However, when radical—rather than incremental—innovations are needed, the diffusion phase may offer the greatest opportunity for improvement.

The Emergent and Transformation Systems Division has been recognized for its achievements and continues to improve upon the strategy that success in innovation can be achieved through education, invention, prototyping, at-sea experimentation, analysis, collaboration, innovation cells, and adoption by the warrior. The division's recognition includes the Warfare Center 2008 Innovation Award; the PEO-IWS 2007 Award for Innovation; the National Society of Professional Engineer's Top 10 Federal Engineer of the Year Award; the Rhode Island Federal Employee of the Year Award; and recently, recognition in USA Today's announcement for New Faces in Engineering.

By leveraging existing systems and COTS equipment, the invention and militarization phases experience rapid turnaround. Striving to ensure that new concepts align within the context of existing DOTMLPF improves the diffusion phase and maintains the focus on requirements, operational concepts, and integration into acquisition planning. Improving the observability of undersea warfare experiments also helps to improve the diffusion phase of innovation, which more quickly arms warfighters with vastly improved capabilities.

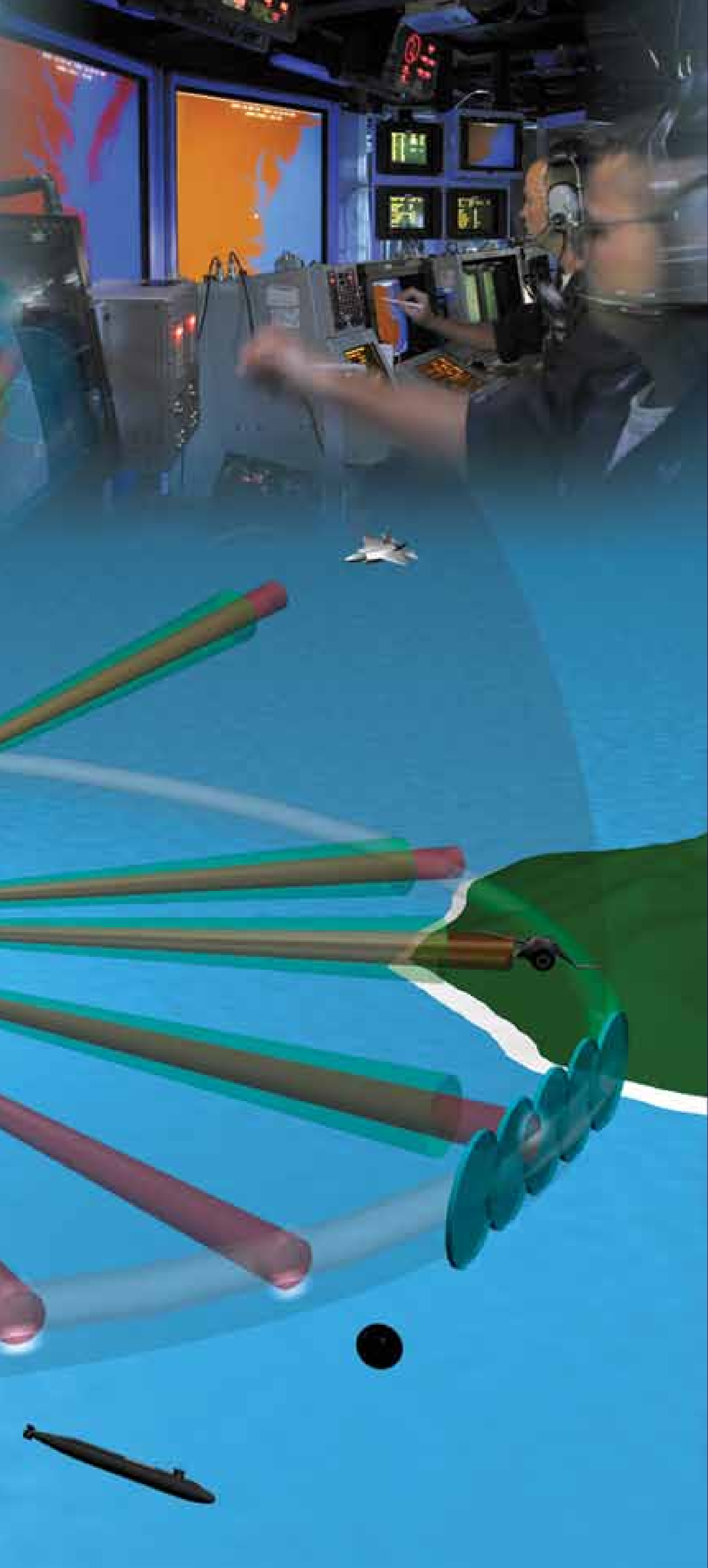
Acknowledgment

The author would like to acknowledge the technical contributions to this article from the engineers at NUWC who worked on the systems discussed, particularly Dr. Michael Obara, Mark Vaccaro, Susan Lashomb, Kristy Moore, and Joe Gouveia.

Figure 11. The Diffusion of Innovation Challenge

Dual-Band Radar Development: From Engineering Design to Production

By Alan L. Tolley and John E. Ball



Overview

The Dual-Band Radar (DBR) Suite is a U.S. Navy program. The suite consists of two radars integrated with a common controller and single interface to the combat system. The DBR radar acts according to combat-system-supplied doctrine, which effectively removes the need for an operator to run the radar, look at a radar display, and make tactical decisions. The radar not only provides fast reaction times, but also removes much of the potential for operator error in threat response.

The radars operate at X-band and S-band, and utilize active array technology, a first for the U.S. surface Navy. The DBR is scheduled for Initial Operational Capability (IOC) in 2014 aboard DDG 1000. The DBR will also be installed aboard USS *Gerald R. Ford* (CVN 78), the lead ship of the CVN 21 program. The DBR program started in 1999 with a contract award for the AN/SPY-3 Multifunction Radar (X-band) to Raytheon. Raytheon recently installed engineering development models (EDMs) of both the X-band and the S-band radars at the DDG 1000 Wallops Island Engineering Test Center (WIETC). Testing on AN/SPY-3 and the S-band Volume Search Radar (VSR) is currently underway. This paper summarizes the effort of transitioning from engineering design to production, discusses the upcoming combat-system integration challenges, and highlights the advantages of the integrated DBR system to the Navy.

System Architecture and Description

The DBR suite is composed of two radars: the AN/SPY-3 Multifunction Radar (an X-band radar) and the VSR (an S-band radar) and contains a central resource manager for both radars. The DBR is connected to the combat system via a single interface. A block diagram of the DBR system is shown in Figure 1. The AN/SPY-3 primarily focuses on horizon search, low-altitude tracking, and missile support (illumination, uplink, and downlink), while the VSR is primarily responsible for volume search and tracking.

The design goals of DBR are to:

- Operate in harsh littoral environments, which often include potentially high-clutter areas, as well as land-based jamming
- Provide automated ship self-defense capabilities against air and surface targets, including low-flying missiles
- Provide robust multimission radar
- Provide advanced electronic protection (EP) capabilities

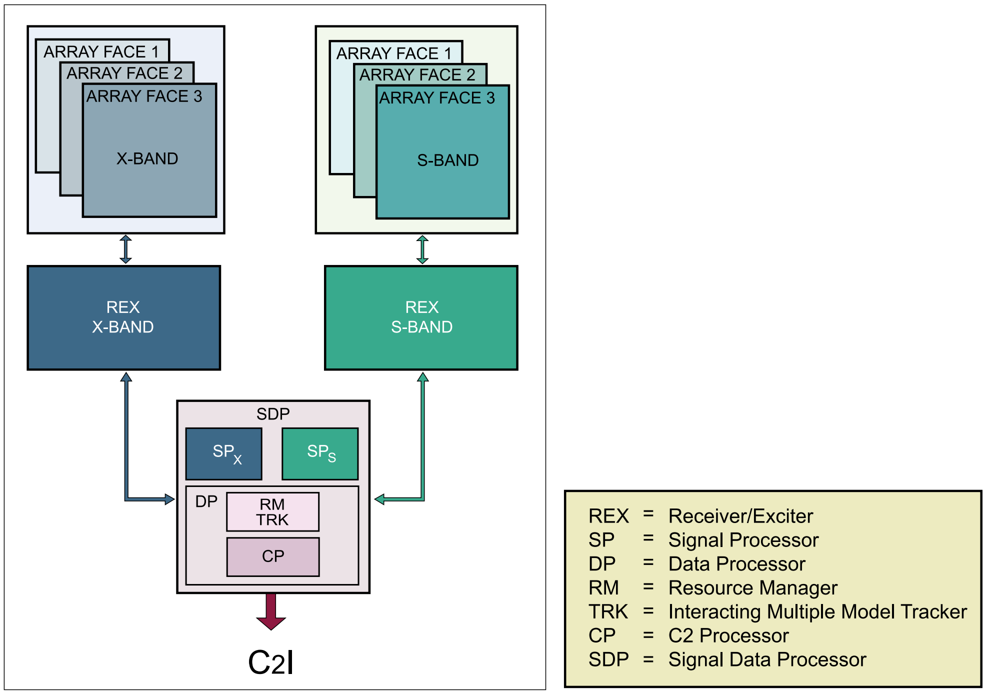


Figure 1. DBR Block Diagram

The AN/SPY-3 consists of three active arrays and the Receiver/Exciter (REX) cabinets above-decks and the Signal and Data Processor (SDP) subsystem below-decks. The VSR has a similar architecture, with the beamforming and narrowband down-conversion functionality occurring in two additional cabinets per array. A central controller (the resource manager) resides in the Data Processor (DP). The DBR is the first radar system that uses a central controller and two active-array radars operating at different frequencies.[1]

The DBR gets its power from the Common Array Power System (CAPS), which comprises Power Conversion Units (PCUs) and Power Distribution Units (PDUs). The DBR is cooled via a closed-loop cooling system called the Common Array Cooling System (CACS). The power and cooling systems are not shown in Figure 1.

The X-band has, in general, favorable low-altitude propagation characteristics, which readily support the horizon search functionality of the AN/SPY-3. A large operating bandwidth is required to mitigate large propagation variations due to meteorological conditions (i.e., evaporative ducting). The X-band arrays are smaller and lighter than the S-band arrays. This allows the X-band radar to be positioned higher, which results in improved performance in low-flyer detection and tracking.[2] The VSR provides a high-power-aperture product (the power-aperture product is a figure of merit of radar systems, the product of the total average radar transmitted power and the antenna area), and sufficiently small beam widths to support accurate target tracking. The VSR's primary role is to perform the volume search function.

The AN/SPY-3 and the VSR are both advanced, solid-state, active phased-array radars. Solid-state arrays offer several advantages:

- Lower transmit and receive losses relative to passive arrays
- Higher operational availability
- Graceful transmit degradation versus a single transmitter system[2]

The REX consists of a digital and an analog portion. The digital portion of the REX provides system-level timing and control. The analog portion contains the exciter and the receiver. The exciter is a low-amplitude and phase noise system that uses direct frequency synthesis. The radar's noise characteristics support the high clutter cancellation requirements required in the broad range of maritime operating environments that DBR will likely encounter. The direct frequency synthesis allows a wide range of pulse repetition frequencies, pulse widths, and modulation schemes to be created. The receiver has high dynamic range to support high clutter levels caused by close returns from range-ambiguous Doppler waveforms. The receiver has both narrowband and wideband channels, as well as multichannel capabilities to support monopulse processing and sidelobe blanking. The receiver generates digital data and sends the data to the signal processors.

The DBR uses IBM commercial off-the-shelf (COTS) supercomputers to provide control and signal processing. DBR is the first radar system to use COTS systems to perform the signal processing. Using COTS systems reduces development costs and increases system reliability and maintainability. Referencing Figure 1, the high-performance COTS servers perform signal analysis using radar and digital signal-processing techniques, including channel equalization, clutter filtering, Doppler processing, impulse editing, and implementation of a variety of advanced electronic protect algorithms. The IBM supercomputers are installed in cabinets that provide shock and vibration isolation. The DP contains the resource manager, the tracker, and the command and control processor, which processes commands from the combat system.

The DBR utilizes a multitier, dual-band tracker, which consists of a local X-band tracker, a local S-band tracker, and a central tracker. The central tracker merges the local tracker data together and directs the individual-band trackers' updates. The X-band tracker is optimized for low latency to support its mission of providing defense against fast, low-flying missiles, while the VSR tracker is optimized for throughput due to the large-volume search area coverage requirements.

The combat system develops doctrine based on the current tactical situation and sends the doctrine to the DBR. The combat system also has control of which modes the radar will perform. Unlike previous-generation radars, the DBR does not require an operator and has no manned display consoles. The system uses information about the current environment and doctrine from the combat system to make automated decisions, not only reducing reaction times, but also reducing the risks associated with human error. The only human interaction is for maintenance and repair activities.

The DBR supports the modes of operation as shown in Figure 2. The primary modes for AN/SPY-3 are horizon search/track while scan, surface search/navigation, periscope detection and discrimination, and environmental mapping. During engagements, AN/SPY-3 also performs precision

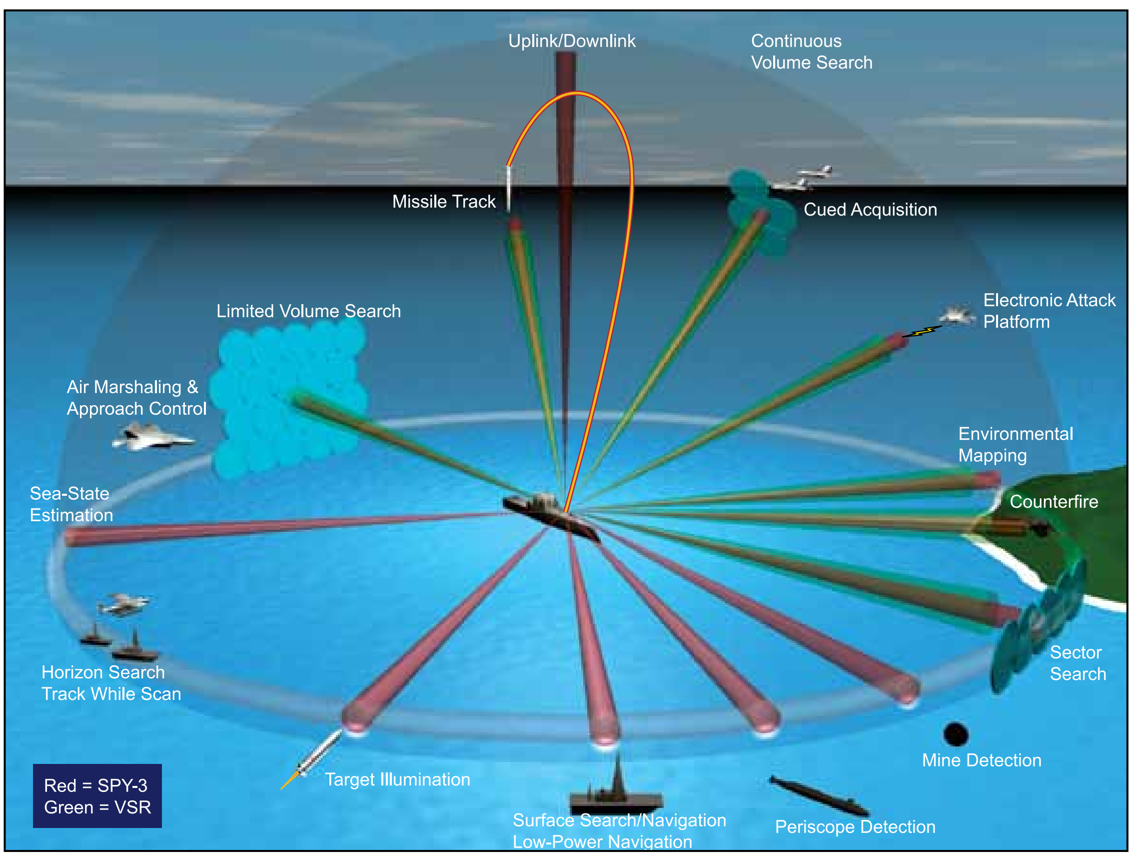


Figure 2. DBR Operating Modes

tracking, ownship missile tracking, missile communications, and target illumination. The primary mode of operation for VSR is continuous volume search, precision tracking, and environmental mapping. Several modes can be performed by either band as directed by the resource manager, such as limited volume search, precision tracking, or cued acquisition. This allows the radar flexibility if one of the bands is taxed due to other modes being performed, such as when the AN/SPY-3 is performing illuminations.

Previously, the Navy utilized separate radar systems for air traffic control (ATC), target illumination, target tracking, surface search and navigation, missile tracking, and environmental mapping. The DBR suite integrates these functions into one system, providing a robust and effective solution for the Navy. An integrated system has several advantages over a collection of separate systems—lower cost, lower weight, lower ship space required, and most importantly, less manning is required.

Engineering Development Model (EDM) Integration & Test

The DBR integration and test effort has been separated into two parallel efforts. The first effort focuses solely on AN/SPY-3, whose development started much earlier than VSR. The second effort focuses solely on integrating VSR. Both systems continue to be integrated and tested separately at Wallops Island until late 2009, when both systems will be integrated to form the DBR.

AN/SPY-3 Integration and Test

This section discusses the integration and testing at Wallops Island on the Self-Defense Test Ship (SDTS), and at the Surface Warfare Engineering Facility (SWEF).

Wallops Island Land-Based Testing

The AN/SPY-3 Development Contract, awarded to Raytheon in 1999, produced an EDM that was installed at Wallops Island, Virginia, in 2003. This installation is shown in Figure 3. At this location, the AN/SPY-3 EDM System was integrated, and full-power radiation was achieved for the first time. Previous subsystem integration activities were limited to single-element radiation inside a near-field range. As the system matured, the effort transitioned from a hardware verification activity to a system functionality test program, which specifically focused on the Air Search and Track functionality. The test program adopted an incremental strategy that began with tracking low-cost targets (e.g., Learjets) and culminated with testing against target drones.

Self-Defense Test Ship (SDTS) Testing

After completing the land-based testing in 2005, the AN/SPY-3 system was shipped to Port Hueneme, California, to be installed upon the SDTS, the decommissioned USS *Paul F. Foster* (DD 964). Figure 4 shows the SDTS and identifies the location of the AN/SPY-3 radar on the ship. The test objectives remained similar, but these tests were conducted in an operational environment with ship-motion and land-clutter backgrounds. The AN/SPY-3 completed its testing program in 2006 but remained on the SDTS until 2008 to observe Ship Self-Defense System (SSDS) testing. The testing, completed while installed on the SDTS, was essential to production decisions and gave insight into the operational environment.

VSR Integration & Test

The VSR development produced an EDM that was installed in the SWEF located at Port Hueneme, California, in 2007. This installation is shown in Figure 5. This test period focused on hardware characterization, including measurements of Effective Isotropically Radiated Power (EIRP) and system stability. (EIRP is a figure of merit for antenna systems and is a way to compare the radiated power of antennas.) In 2008, the system was shipped to Wallops Island, Virginia, to be installed in the WIETC, shown in Figure 6.

Figure 3. AN/SPY-3 Wallops Island Installation

Figure 4. AN/SPY-3 Self-Defense Test Ship Installation

Figure 5. VSR Surface Warfare Engineering Facility Installation

Figure 6. Dual-Band Radar Wallops Island Engineering Test Center Installation

Platform Integration

The DBR is being integrated into both the *Zumwalt*-class destroyer and the *Ford*-class aircraft carrier. Each platform introduces its own set of design considerations, which range from prime power type to sensor priority differences. The examples listed in this section are not intended to be complete; they represent only a sampling of the platform design considerations for both *Zumwalt* and *Ford*.

DDG 1000 Zumwalt-*Class Destroyer*

The physical arrangement of the sensors in the *Zumwalt* deckhouse is illustrated in Figure 7. To accommodate integration into the *Zumwalt* class, the DBR design has been uniquely influenced in the areas of prime power type, array structure, and VSR radome design. With the introduction of the Integrated Power System (IPS) for *Zumwalt*, the 440-VAC EDM design was changed to accommodate the ship-power-supplied 4160 VAC. The CAPS design is being updated to accommodate the voltage change.

CVN 78 Gerald R. Ford-*Class Aircraft Carrier*

The physical arrangements of the sensors in the *Ford*-class island are illustrated in Figure 8. To accommodate integration into *Ford* class, the DBR design has been uniquely influenced in the areas of prime power type and sensor priorities. Similar to the design changes in *Zumwalt*, *Ford* class will supply CAPS with 13.8 kVAC. Design updates to CAPS are in process to accommodate this change.

In addition to being the primary antiair warfare (AAW) sensor for the *Ford* class, DBR is also the primary ATC sensor. To accommodate this added functionality, DBR has added a short-range search fence to the baseline functionality set that runs concurrently with other functionalities, such as long-range volume search and track, horizon search and track, etc. To date, the combat system and ATC mission areas have had dedicated sensors on aircraft carrier platforms. The concept of sharing the DBR across mission areas is a new concept and requires careful consideration of how the system is integrated.

Future Challenges

In order to successfully deliver the DBR to the fleet, a number of activities will be accomplished over the next several years, including the completion of the radar integration and test program. Results from testing to date—along with

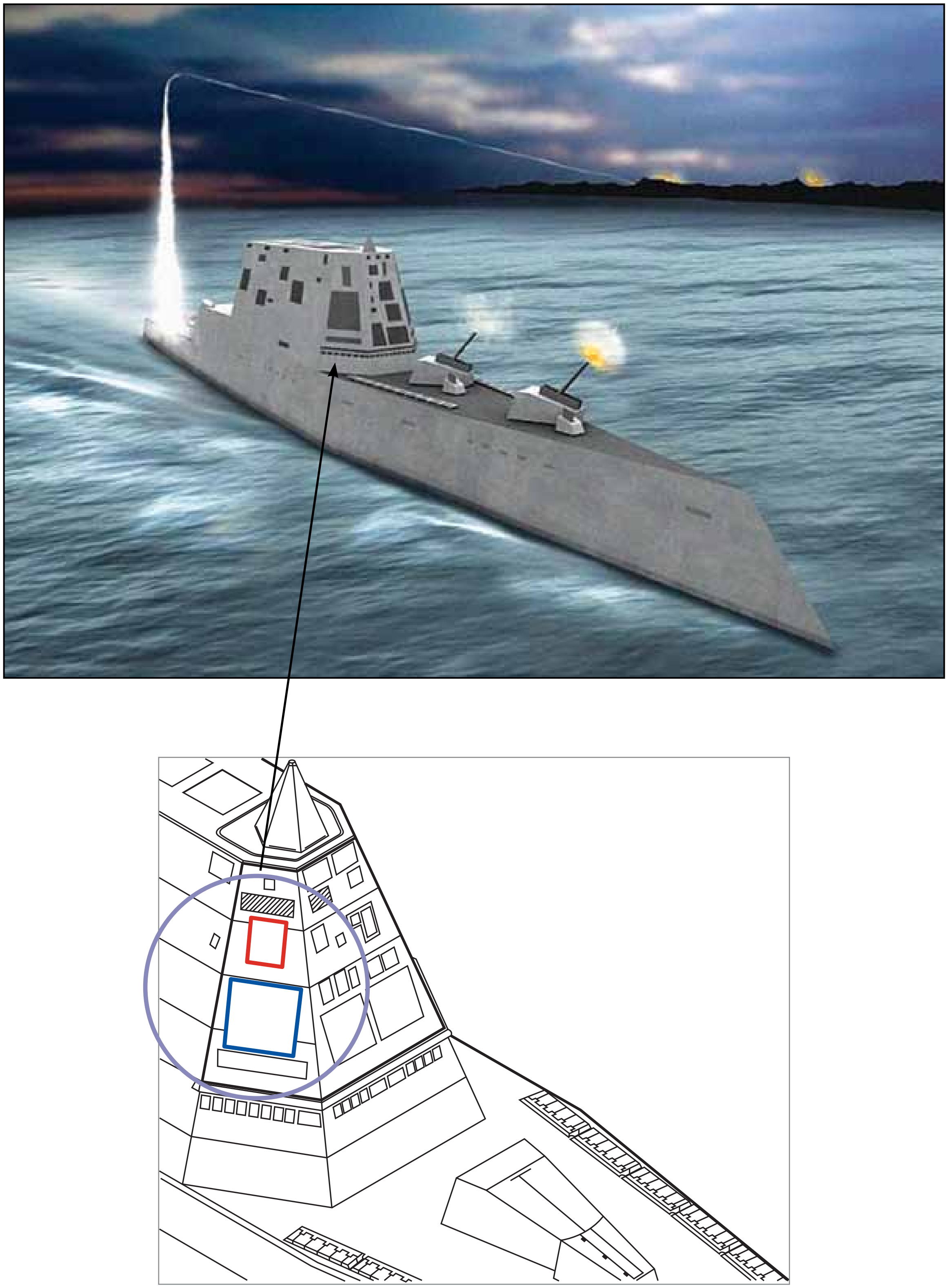


Figure 7. DDG 1000 USS *Zumwalt* DBR Installation Drawing—AN/SPY-3 is shown in red, and VSR is shown in blue.

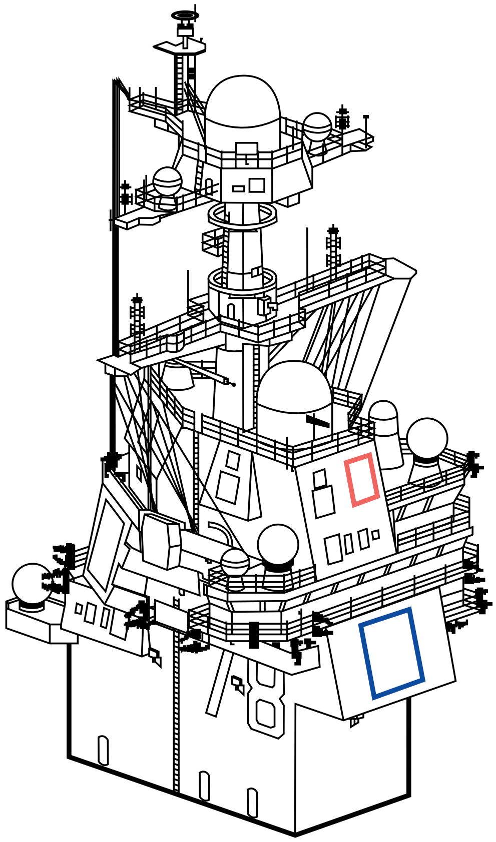


Figure 8. CVN 78 DBR Installation Drawing—AN/SPY-3 is shown in red, and VSR is shown in blue.

cost reduction, risk mitigation, and production activities—have been incorporated into the production designs. The DBR has entered the beginning stages of production, and the challenges of producing units in sufficient quantity will continue as this transition from prototype to production occurs. Combat-system integration activity for both *Zumwalt* and *Ford* class is a significant future activity. The combat-system integration activity will not be limited to connectivity of the system but to also collaboratively work with the combat system(s) to ensure that the advanced capability introduced by DBR is fully integrated into the combat system.

Conclusions

The DBR is a highly integrated system, providing the Navy with a powerful volume and surface-search radar system. The DBR is the first radar to use COTS supercomputers to perform signal-processing functions, providing a cost-effective, robust solution. The DBR is also the first dual-band, active-array radar suite with a central controller, providing advanced capabilities and flexibility to the Navy. The DBR acts automatically using combat-system-supplied doctrine, and DBR does not need a dedicated operator. This system reduces system-level reaction times and removes much of the potential for operator error in threat response, compared to previously fielded Navy radar systems. This results in reduced operating costs and fewer chances for human error. The DBR is designed with graceful degradation wherever possible, providing both reduced operating costs and a robust system for the Navy. The MFR and VSR radars are currently being tested, and integration with the combat systems is planned in the future.

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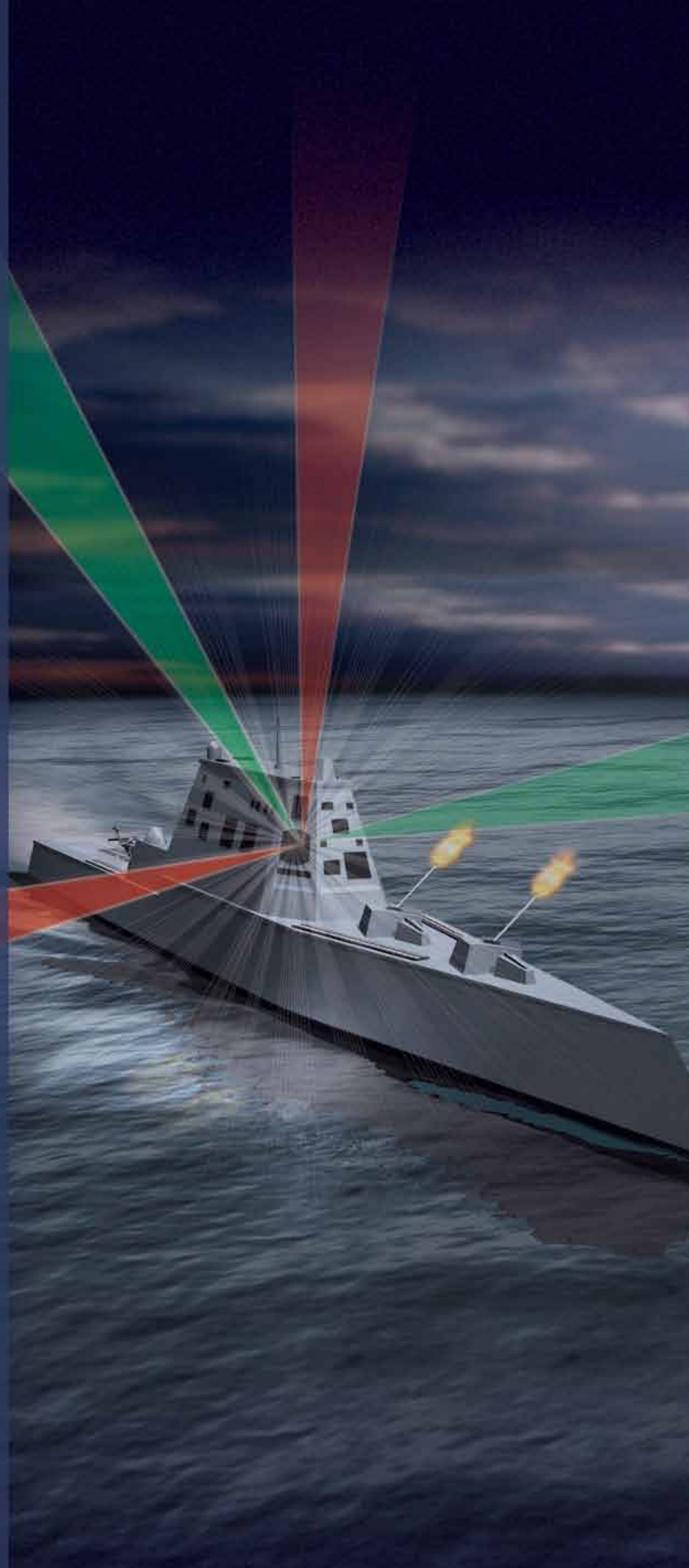


International Treaty Verification: Cobra Judy Replacement Program

By Penny Moran and Chris Reasonover

Figure 1. Cobra Judy Aboard USNS *Observation Island*

The Cobra Judy radar system provides long-dwell, foreign ballistic-missile data collection in support of international treaty verification. Cobra Judy, aboard U.S. naval ship (USNS) *Observation Island* (shown in Figure 1), has been in service for many years, with the ship now over 56 years old. Consequently, both the system and the ship are in need of replacement.

Cobra Judy Phased Array Radar

The Cobra Judy Replacement (CJR) Program includes the design, development, and acquisition of a functional replacement ship and mission equipment (ME) suite for the current Cobra Judy and USNS *Observation Island*. The CJR's treaty verification mission will remain the same as the system it replaces, and it will continue to provide worldwide, high-quality, high-resolution, multiwavelength radar data. The systems aboard the replacement ship will include high-power, instrumentation-class, X-band and S-band phased-array radars and the necessary ancillary equipment to support the mission. A close-up of Cobra Judy S-band phased array and X-band dish antenna is shown in Figure 2. The X-band radar and its antenna dimensions are shown in Figure 3, with the array halves being test-fit for the X-band array shown in Figure 4.

Both the X-band and S-band radars will employ a variety of waveforms and bandwidths to provide operational flexibility and high-quality data collection. The X-band radar will provide very high-resolution data on particular objects of interest, while the S-band radar will serve as the primary search-and-acquisition sensor and will be capable of tracking and collecting data on a large number of objects in a multitarget complex. The S-band antenna dimensions are shown in Figure 5, with an overall size very similar to the X-band antenna.

A common back end (CBE) will handle all controls and signal processing for both X- and S-band arrays. The CBE includes:

- Displays
- Processing Software and Equipment
- Communication Suite
- Weather Equipment

Figure 2. Close-Up of Cobra Judy S-Band Phased Array and X-Band Dish Antenna

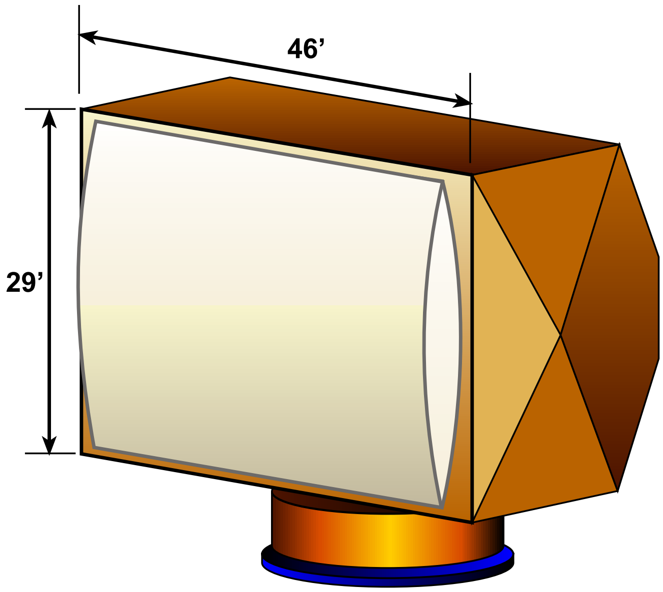


Figure 3. X-Band Antenna

Figure 4. Test-Fit for Upper and Lower Halves of the X-Band Array

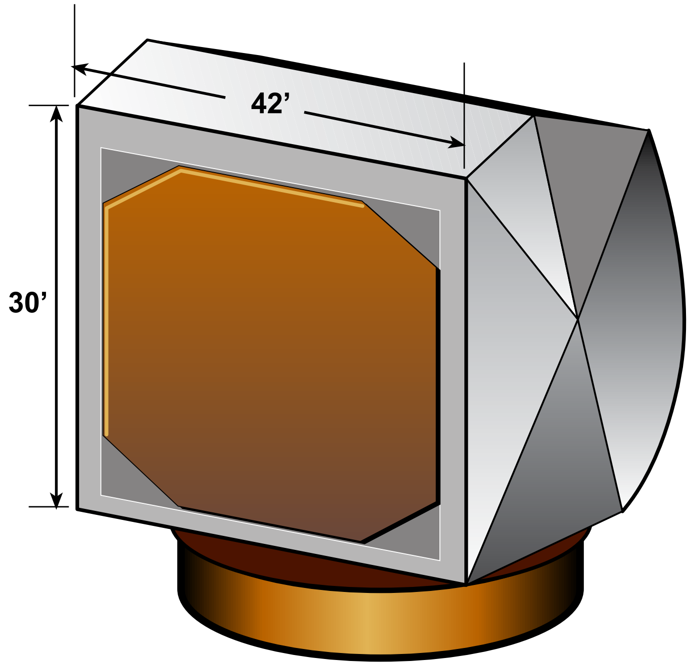


Figure 5. S-Band Antenna

Centralizing the software and processing equipment maximizes code reuse between the two radars and reduces overall cost for the system. Many of the CBE components are designed to be common, modular, and open between the two radars. The CBE will also be equipped with various simulation and test modes to support maintenance and training. The CBE is depicted in Figure 6.

Raytheon Integrated Defense Systems (Raytheon IDS) is developing the X-band radar and CBE ME, with Northrop Grumman Electronic Systems (as a directed subcontractor) developing the S-band antenna, pedestal, and antenna servo control system. The CJR ME suite will be installed on a T-AGM 25 platform specially outfitted for the mission, as shown in the artist's concept in Figure 7. The ship is being constructed by VT Halter Marine in Pascagoula, Mississippi. When ship construction is complete, it will move to Ingleside, Texas, for installation of ME, including the heavy-lift operations of installing the pedestals and arrays. Like the current USNS *Observation Island*, the new ship—recently named USNS *Howard O. Lorenzen*—will be a white-hull, noncombatant. CJR's initial operational capability (IOC) is set for 31 December 2012.

Engineers at the Naval Surface Warfare Center (NSWC) Dahlgren helped to lead design efforts and continue to support development and testing by leveraging core technical capabilities in:

- Requirements Development and Validation
- Systems Engineering
- Software Development
- Safety and Environmental
- Electromagnetic Interference / Electromagnetic Compatibility (EMI/EMC)
- Human-Systems Integration (HSI)

Requirements development included managing a diverse technical team made up of both government and contracted engineering-support personnel, while requirements validation was realized through in-house modeling and simulation (M&S). These and other efforts included both direct program office leadership roles and specialized engineering support at the working level.

Recognized for its rigorous radar systems engineering, NSWC Dahlgren was appointed as the lead or deputy in several of the program office's integrated product teams (IPT) from the program's start. As the X-band IPT lead, NSWC Dahlgren was responsible for developing key requirements, monitoring functional requirement allocations, and maintaining oversight through design and manufacturing. NSWC Dahlgren also supported the S-band IPT as deputy lead and developed many of its key requirements. Both IPTs leveraged NSWC Dahlgren's expertise in radio frequency (RF) propagation to develop operational performance requirements for both radars under a range of environmental conditions.

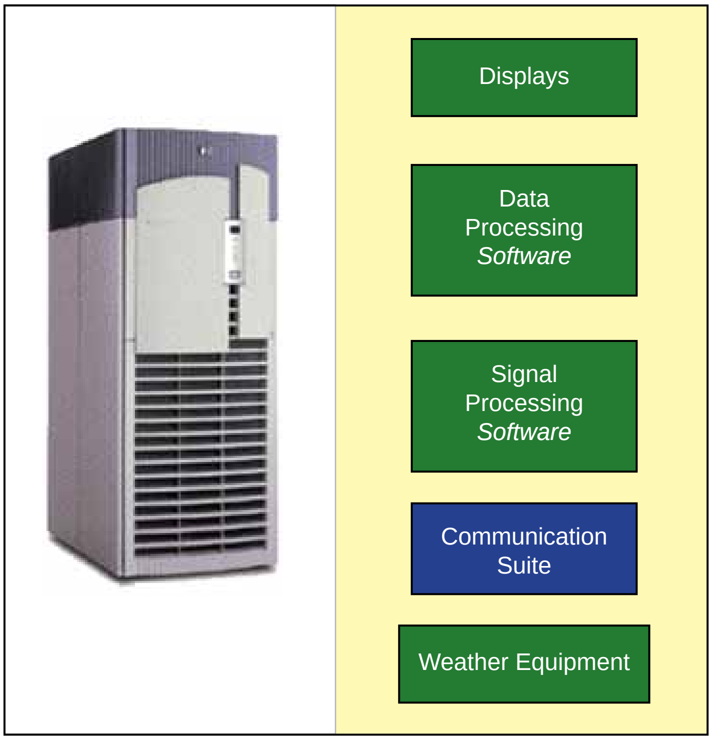


Figure 6. Common Back End (CBE)

As the CBE IPT lead, NSWC Dahlgren led and continues to oversee development of the software that will integrate the X- and S-band radars. Early in the program, NSWC Dahlgren engineers maintained a constant presence at Raytheon IDS to participate in the software development process and to collect metrics for the program office. This allowed for early detection, reporting, and resolution of software development issues. NSWC Dahlgren also led the CJR Operations IPT. This role required frequent site visits to all subcontractors to witness manufacturing and developmental testing of the ME, which included construction and factory acceptance testing of the antenna pedestal, antenna backstructure, X-band array plates, cooling equipment, and power equipment.

NSWC Dahlgren further served as the deputy lead in the Integration and Test IPTs and continues to serve as deputy lead for integration. As the Test IPT deputy, NSWC Dahlgren reviewed test plans and procedures, witnessed factory acceptance and specification sell-off testing, and interfaced with both the Navy and Air Force operational test agencies to write the Test

Figure 7. Artist's Concept for USNS *Howard O. Lorenzen*

and Evaluation Master Plan (TEMP), further coordinating approval through the Navy, Air Force, and Office of the Secretary of Defense (OSD). The Test IPT deputy also chaired the M&S accreditation board, which imposed a rigorous verification, validation, and accreditation (VV&A) process to prime contractor-proposed models to be used for final requirements sell-off. As the Integration IPT deputy, NSWC Dahlgren served as the government liaison between the program office and Raytheon IDS to coordinate witnessing of developmental tests in support of requirement sell-off and to maintain sell-off evidence for government acceptance. NSWC Dahlgren engineers also developed the sign-off process for the program office.

NSWC Dahlgren additionally served the CJR program office in a number of unique and important areas outside of the IPT lead and deputy roles. Early in the program, NSWC Dahlgren served as a liaison between ME and ship requirements development, subsequently participating in the ship source selection process as the program office's representative and ME expert. NSWC Dahlgren was also a major contributor to the milestone B/C documents, such as the acquisition plan, acquisition strategy, integrated logistics support plan, systems engineering plan, and the TEMP. In addition, NSWC Dahlgren engineers drafted the initial security class guide for the program office and participated in the final contract negotiation with Raytheon IDS.

Other engineering support included the CJR Principal For Safety (PFS), environmental compliance analysis, EMI/EMC studies, and HSI reviews. As PFS, NSWC Dahlgren served as the CJR Program liaison to the Weapon System Explosives Safety Review Board (WSESRB). Once the PFS role was completed, NSWC Dahlgren continued as the lead for safety on the program. NSWC Dahlgren also performed analyses to confirm CJR's compliance with international pollution control standards. One goal of these analyses was to verify the ME's ability to endure the corrosive environment produced by a maritime environment and ship stack gases. NSWC Dahlgren was also responsible for all EMI/EMC topside studies. The EMI/EMC study included analysis to minimize co-site interference between the two radars and the between the radars and communications suite, as well as the ship's navigation and safety systems. This analysis included investigation and mitigation of potential issues with off-board RF emitters. Furthermore, NSWC Dahlgren was, and continues to be, the lead for dealing with domestic and international frequency spectrum management among CJR, the operational Navy, and all other potential sources of interference.

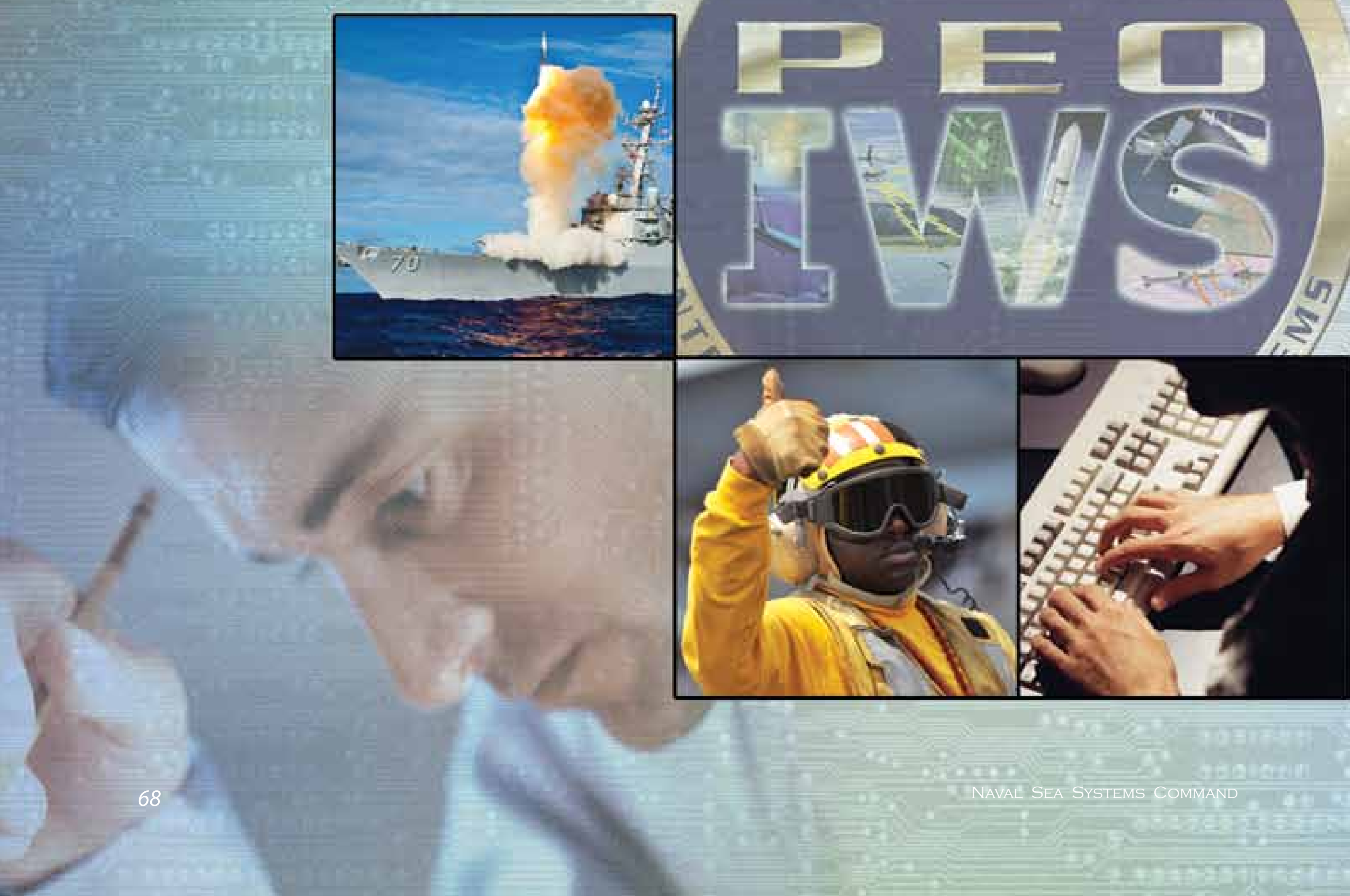
One of NSWC Dahlgren's more critical engineering support roles is to serve as the government clearinghouse for all CJR contract deliverables and working documents by hosting both unclassified and classified websites. These websites enable document and data sharing day and night across multiple sites, thereby facilitating the timely turnaround of documents, comments, and analysis products. These websites additionally provide a common, controlled document repository for all CJR data supporting government and industry.

In replacing the aging Cobra Judy and USNS *Observation Island*, the Navy, NSWC Dahlgren, and the Air Force are ensuring that CJR will succeed in performing the critical mission of international treaty verification over the coming decades.

Cobra Judy Phased Array Radar

Program Executive Office Integrated Warfare Systems Above Water Sensor Directorate Common Digital Sensor Architecture Design Initiatives

By John Schofield




Legend
CDSA Core Elements
Legacy Sensor Elements
Shore-based Elements
Ship Supply Systems
Combat System
TSTS
Legacy Sensor Elements
CDSA Functions:
Sensor Functions:
IDE
HMI

The Program Executive Office Integrated Warfare System above Water Sensor Directorate (PEO IWS 2.0) initiated the Common Digital Sensor Architecture (CDSA) project to address long-term reliability, maintainability, and availability (RMA) issues associated with deployed above-water sensors caused by systemic obsolescence. The Naval Surface Warfare Center (NSWC) Crane Division was tasked by PEO IWS 2.0 to lead the CDSA project to assist with the alignment of sensor support solutions and the development of the support infrastructure to achieve and sustain operational effectiveness of sensor systems. Through the successful implementation of the CDSA effort, PEO IWS 2.0 is providing a means to eliminate sensor-unique reengineering efforts; provide stability for out-year funding requirements; and consolidate contracts, engineering, and support efforts.

The CDSA project is divided into three primary efforts: CDSA Core, Shore-Based Product Data Management (PDM), and a CDSA Sensor Integration Kit. The CDSA functional block diagram, contained in Figure 1, illustrates the interaction of CDSA functional elements.

The CDSA Core comprises common shipboard elements consisting of human-machine interface (HMI), maintenance and support functions, an integrated data environment (IDE), a sensor tactical host function, and standardized interfaces. The CDSA Core provides a common sensor look, touch, and feel, while eliminating processes that drive knowledge and skill requirements. Additionally, the CDSA Core automates the maintenance and supply support process; integrates technical and support data to eliminate advanced training requirements; captures accurate RMA sensor data; and provides a common development platform, enabling a reduction to manpower, personnel, and training costs. A common architecture and accurate RMA data enable the Navy support community to effectively implement and manage a support strategy to achieve and sustain operational effectiveness objectives.

The Shore-Based PDM provides the capability to collect, process, and manage all relevant system

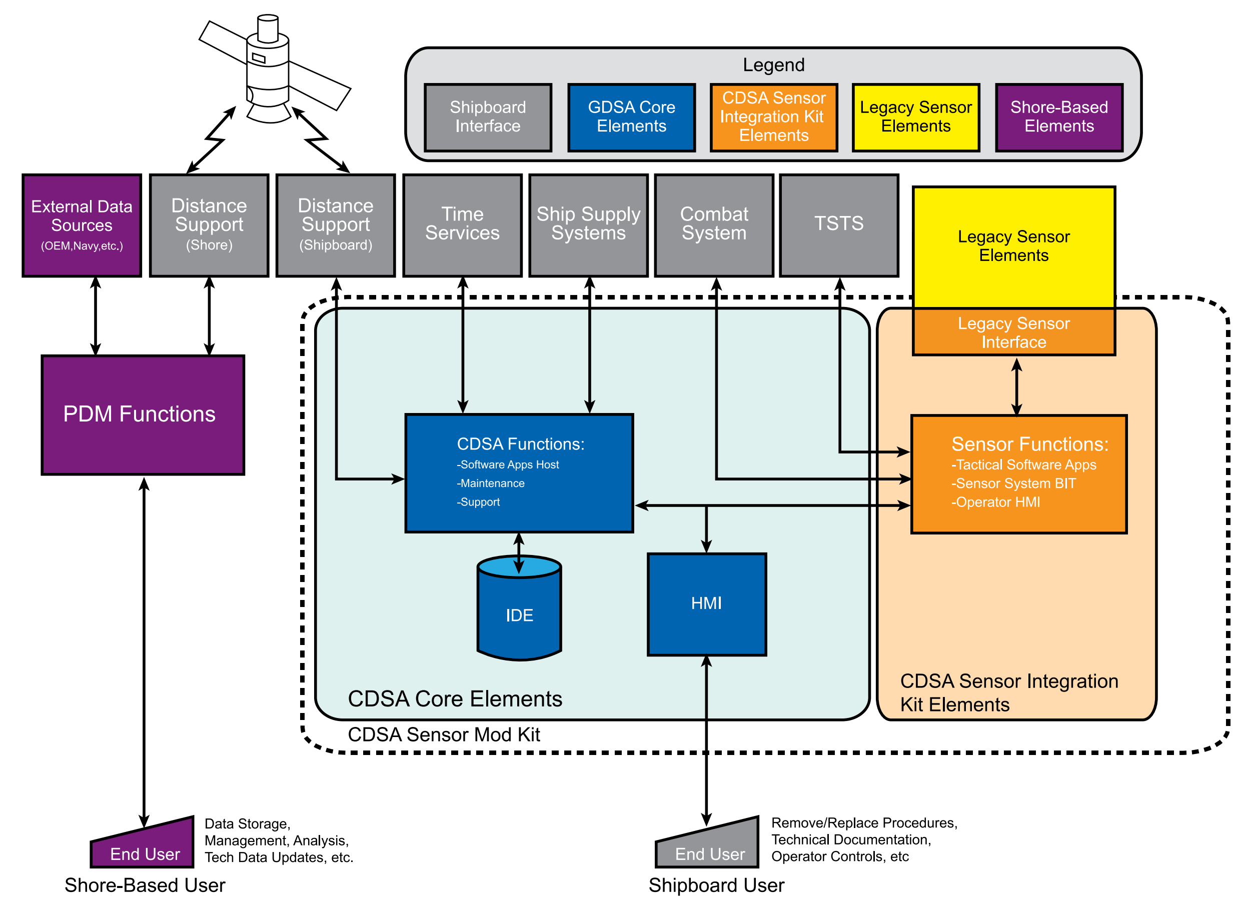


Figure 1. Common Digital Sensor Architecture Functional Block Diagram

data required to implement an effective sustainment strategy across all designated Above-Water Sensors' life cycles. The PDM also provides the capability to synchronize and extract data from ship to shore through utilization of existing Navy Distance Support architecture.

The Sensor Integration Kit includes the hardware and software components required to integrate the CDSA Core into the sensor system. The integration of CDSA transitions sensor applications' execution to general-purpose processors, and introduces and expands full system built-in-test and built-in-measurement designs to achieve sensor supportability requirements.

The CDSA design effort establishes a common modular architecture using Navy Open Architecture guidelines, standardized interfaces, and common hardware. The alignment of technical architectures across sensor systems enables synchronization of efforts across sensor systems. The development of portable sensor applications reduces the risk of technology refresh and technology insertion in the out years. In addition, the CDSA design effort reduces system maintenance requirements, required shipboard technical skills, and workload requirements. Maintenance requirements are reduced by expanding the sensor self-monitoring capability by embedding all required technical information into the system and by providing a design solution that eliminates the requirements for pipeline training, technical training equipment, and technical manuals. The ultimate goal is to design the CDSA such that an apprentice-level technician can maintain the system. This would enable the same technician to maintain multiple sensor systems.

Another objective of the CDSA project is to establish a common set of support measures of effectiveness (operational availability, ownership cost) and then manage logistics support to these measures in an IDE, which is critical to providing a common life-cycle support strategy. Visibility into sensor systems to accurately report and assess RMA of the system is critical in meeting fleet requirements and in addressing and sustaining fleet needs. Standardization and the accessibility of accurate data is the key enabler. Not only does standardization and accessibility of sensor data allow for a network of integrated sensors, it also provides visibility to assess the effectiveness of the support solution.

In summary, to PEO IWS 2.0, CDSA provides a common core capability supporting improved operability and maintainability, as well as providing accurate RMA data to monitor sensor support solutions. This approach provides continuous visibility into the system to identify where program resources should be invested. For the fleet, CDSA provides an integrated support solution that sustains operational availability within affordable cost. For the technical community, CDSA provides a modular software-centric and net-centric system to act as a transition platform for technology. For the supply support community, CDSA provides RMA data to perform supply chain management to ensure that support strategy sustains system operational availability at cost.

International Programs

By Michael Madatic

Entering the 21st century, the U.S. has come to deal with the reorganization of Russia and the growth of China, as well as smaller rogue states. As part of an active foreign policy, the Navy has pursued international cooperative efforts to meet shared maritime interests. The Naval Surface Warfare Center (NSWC) Dahlgren has been committed to advancing radar projects both within the Department of Defense (DoD) and alongside allied nations over the last several years. And like the U.S. Navy, navies of the U.K. and Australia are fielding advanced active phased array radars.

U.K./U.S. Advanced Radar Technology Integrated System Test Bed (ARTIST)

The U.S. and U.K. are cooperatively conducting research and development of advanced maritime active phased array radars to support future maritime radars or upgrades to existing systems. Specifically, the U.S. and U.K. are developing and testing two advanced phased array radar demonstrators under the ARTIST program. Technologies to be applied include adaptive active digital array, signal-processing, digital beamforming, high-range resolution integration techniques, and radar controls. Testing will begin in the spring of 2010 at Wallops Island, Virginia.

The U.K. has invested heavily in the development of digital array architecture (i.e., analog-to-digital conversion), as well as digital beamforming techniques through critical experiments and algorithm development over the past 20 years. These technologies included the construction of an active S-band radar demonstrator and corresponding radar controls, including the advanced signal-processing and beamforming techniques. These developments were initially conducted by the U.K. under the Multifunctional Electronically Scanned Adaptive Radar (MESAR) I and II programs. By establishing a cooperative program with the U.K., an existing and proven technology can be expanded upon by the U.S. Navy for the development of next-generation radars.

U.S./U.K. ARTIST cooperation provides risk reduction and facilitates the potential use by the U.S. of advanced digital phased array developments for air and missile defense radars. The ARTIST program also provides risk reduction to the U.K. development of the SAMPSON radar. The technologies being developed under the ARTIST program, when combined, will provide a vast improvement to today's sea-based radar systems. A depiction of the SAMPSON Radar is shown in Figure 1.

Benefits from these bilateral cooperative efforts are many and include:

Figure 1. Sampson Radar

- The incorporation of the U.K.'s technological resources (industry/laboratories) and cost sharing of technology maturation are common to both nations.
- Advanced U.K. digital radar technology permits optimization of U.S.-developed high-powered phased array radar.
- The U.K. contribution will provide enhanced and specialized digital adaptive beamforming, thereby reducing the U.S. investment required to fulfill U.S. Navy requirements.
- The output of this cooperative research and development effort represents a quantum increase in adaptive nulling, clutter rejection, and sidelobe cancellation capability over current U.S. analog-based radars.
- The program's resulting critical technologies can be matured in the near term and introduced into new radar designs or as an upgrade backfit to existing radars.
- Cooperation accelerates development schedules while providing significant cost avoidance through cross-capture of complementary and previously completed nonrecurring engineering.

British Aerospace Systems, Qinetiq, and Roke Manor Research are developing the U.K. version of the ARTIST test bed. Lockheed Martin is developing the U.S. version of the ARTIST test bed (see Figure 2). Roke Manor (U.K.) is also a key partner contributing to the development of a distributed receiver (see Figure 3), while BAE is providing the narrow-band, medium-band exciter to the U.S. ARTIST.

Australia/U.S. Phased Array Radar (AU.S.PAR)

In the late 1990s, the Royal Australian Navy (RAN) invested in the development of a solid-state radar system for potential application as a midlife upgrade to the Australian Navy's ANZAC-class ships. This Australian radar development and demonstration effort, termed CEAFAR, was of interest to the U.S. since the resulting radar was one of the first fully functioning S-band solid-state radars in the world. The specific radar that the Australians developed was an engineering development model (EDM) containing two faces of a planned six-face system and low-power transmit/receive (T/R) modules. The Australian EDM system was installed on a RAN ship and completed a very successful at-sea test program. Since the completion of the at-sea test demonstration, the RAN

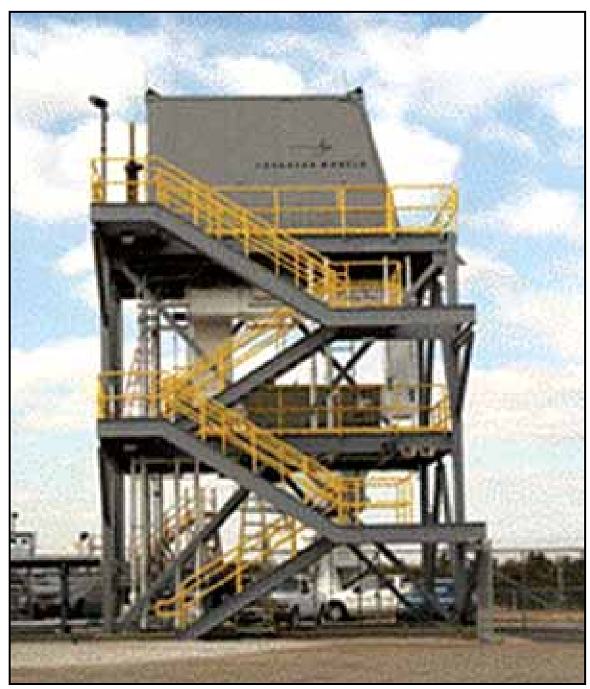


Figure 2. Lockheed Martin ARTIST Test Bed

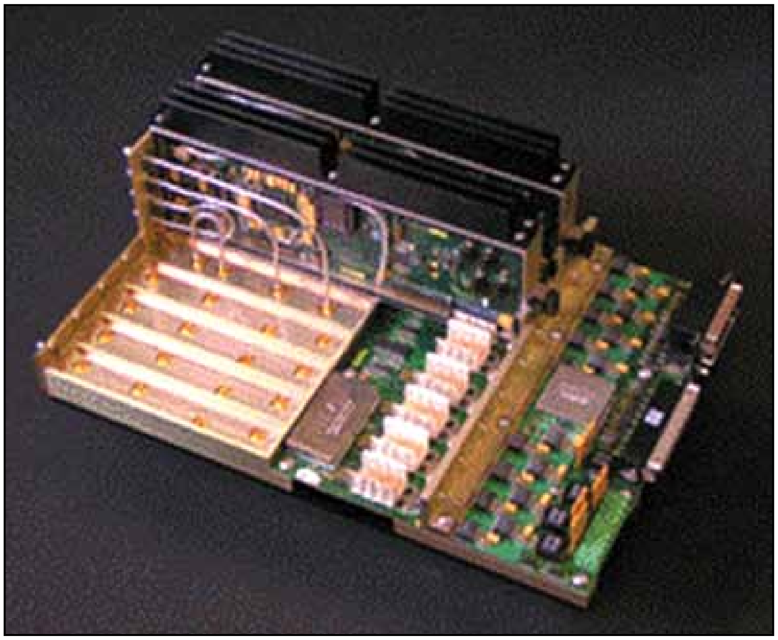


Figure 3. Roke Manor Receiver

approved the midlife upgrade to the ANZAC Class that included procurement of 10 CEAFAR systems from CEA Technologies, Pty, Ltd. A photo of CEAFAR is shown in Figure 4.

In March 2002, under the direction of John J. Young, Jr., then Assistant Secretary of the Navy for Research, Development, and Acquisition, PEO IWS 2.0 (Above-Water Sensors) sent a team of engineers and scientists to Australia to investigate the CEAFAR technology and consider the potential application to future U.S. radar developments. The U.S. team verified that the technology was innovative and realized that the Australian methods for development and manufacturing were very different than those employed by U.S. industries. The U.S. Navy quickly concluded that the U.S. could gain from cooperation with the Australian CEAFAR solid-state radar technology development.

Maritime solid-state radars are generally manufactured on a single faceplate. The single faceplate provides a very rigid structure to hold the radiating elements, with structure flatness requirements as small as 10 mils across the entire aperture. Each face of a solid-state radar typically has an off-array power system, receiving system, and a signal-processing system, all controlled with a digital computer.

In the case of CEAFAR, a process to segment the aperture was developed, allowing a radar to be built from small building blocks (about 12 inches by 12 inches) to the full size required. Each building block is called a tile. The tile includes the receive system and the signal-processing system. The unique Australian tile concept significantly simplifies the manufacturing process of the antenna.

The U.S. and Australian governments ratified the Australia–U.S. Phased Array Radar (AU.S.PAR) Project Arrangement (PA) in April 2005 to develop a medium-power and a high-power version of the tile concept. The high-power version was subsequently cancelled in 2007 due to poor power amplifier performance. The U.S. interests in the cooperative project are focused in five key technology areas for the medium-power project:

1. ***Segmented Aperture***—Understand the process involved in building a large array from small building blocks
2. ***Calibration Methodology***—Examine the process used to calibrate a segmented aperture.
3. ***Pulse-Modulated Power Supply***—Develop an efficient and inexpensive power supply to be used in the tile concept

Figure 4. CEA-FAR Onboard HMAS *Arunta*

4. ***Field-Programmable Gate Arrays (FPGA)-Based High Throughput Signal Processing***—Develop a field-programmable gate array base signal-processing system embedded in the tile.
5. ***Vector Modulator Beam Steering***—Develop a beam-steering capability based on vector modulators that allow steering during transmitted pulses.

The medium-power version of the tile concept commenced test in June 2006.

The Australian company, CEA Technologies, Pty, Ltd, is responsible for the development of all aspects of the AU.S.PAR project. Each of the key technology efforts identified above is jointly developed via cost sharing and is thus usable by both countries. There is no U.S. industry directly involved in the AU.S.PAR project; however, Northrop Grumman has invested heavily in CEA Technologies.

International Program Transition

A key concern of international programs is the ability to transition individual developments into radar programs within each country. If a cooperative program produces a new design, develops a new algorithm, or improves the state of knowledge in a particular technology, it is important that these developments migrate to appropriate radar programs. For research-based projects that are risk-reduction efforts, it may well be concluded that the technology is not the right technology to be inserted into a subsequent development effort. This is also valid output from such projects.

For the ARTIST program, the transition path has already had some success in both the U.S. and the U.K. The U.K. continues with the required development for the SAMPSON radar. To a large degree, the digital technologies of the ARTIST program are already integrated with the SAMPSON radar. Within the U.S., the transition is much more subtle. Lockheed Martin is developing the midlife upgrade of the SPY-1 system and, as part of this design upgrade, the receiver components can be traced to the ARTIST program.

The AU.S.PAR program also has celebrated some success. The tile design and manufacturing process, as well as the associated calibration techniques, are a product of the CEAFAR program. The CEAFAR radar system is destined to be implemented in the midlife upgrade of the ANZAC destroyers. The U.S. has not yet transitioned the technology gains to date; however, each technology is undergoing evaluation for future new radar developments.

Clearly, warfighters representing allied countries benefit tremendously by participating in cooperative research and development programs. These navies benefit not only by having more powerful and more capable radar systems, but international compatibility and interoperability among these systems improves considerably as well.

Rapid Prototyping of Radar Signal Processing

By David Leas

Military sensors employ signal processors to take raw information gathered by the sensors to produce data that can be used by warfighters to gain battlespace awareness. Signal-processing algorithms are typically mathematically intensive, and thus, are the most computationally challenging algorithms seen in military systems. Additionally, the quality of battlespace awareness achieved is often directly related to the complexity built into the signal processor.

Traditionally, the most demanding sensor signal-processing applications have been hosted in hardware-based processing systems. These hardware-based solutions were often constructed using application-specific integrated circuits (ASICs) that required a very high initial investment cost for nonrecurring engineering. This resulted in designs that were prone to obsolescence due to the limited availability of the components over the long life spans of the military system. Recently, the Navy has begun to use digital devices known as field-programmable gate arrays (FPGAs) in radar and electronic warfare sensor signal-processing applications previously solvable only with ASIC-based solutions. Unlike ASICs, FPGAs allow the creation of digital logic that is reprogrammable. Hardware using these devices thereby has flexibility similar to software, which allows the developer to test and upgrade algorithms without the expense and risk associated with fabricating a custom chip each time a change needs to be made. The downside of this flexibility, however, is that in addition to the design challenges inherent in creating hardware, FPGA development adds many of the difficulties found in software development.

Typically, FPGA designs have been developed using a hardware description language (HDL) such as VHDL (Very High-Speed Integrated Circuit (VHSIC) Hardware Description Language). This code needs to be validated for functionality and syntax in a way very similar to conventional software. However, unlike software, in order to validate the design, a tool called an HDL simulator needs to be employed. An HDL simulator uses a special piece of HDL code called a test bench to stimulate the system under test, which allows the simulated system outputs to be validated. After functional validation, the code created with this process is then synthesized to a form suitable for implementation of the design as digital logic in the FPGA.

As an alternative to conventional VHDL design for FPGAs, the vendor Xilinx has created the System Generator for Digital Signal Processing (DSP) development tool that allows for creation of FPGA designs in the Mathwork's Simulink environment. Simulink is a tool that allows for the graphical creation of algorithms using block diagrams known as blocksets and for the subsequent simulation of the designs to ensure proper functionality. Another important feature of Simulink is its link with Mathwork's MATLAB environment. MATLAB is the most widely used tool to model military and commercial signal-processing algorithms and has become the de facto standard for DSP design. The integration of MATLAB with Simulink allows the developer to use code and tools created in MATLAB to stimulate and analyze algorithms developed in Simulink.

The System Generator tool creates functional VHDL code from the Simulink environment using a special blockset developed by Xilinx. Being integrated into Simulink, it allows the developer to test and examine designs through the integration with MATLAB. The developer is able to inject test vectors into the system from the MATLAB workspace and export system outputs to the MATLAB workspace. This ability facilitates a much faster design cycle by moving much of the testing that is normally done with VHDL test benches and simulators to validate functionality of VHDL code to testing in the Simulink/MATLAB environment. By way of illustration, Figure 1 shows a small System Generator design of a component known as a digital down converter that is used in many radar and electronic warfare signal-processing systems.

The System Generator design flow takes advantage of the tight integration of Simulink and MATLAB to realize time savings in the development and validation of FPGA algorithms. A baseline software simulation in MATLAB of the desired system functionality is created that is used to compare with the output of the System Generator model. As each subsystem is completed in Simulink using the System Generator blockset, it can immediately be verified against the MATLAB simulation of the system by replacing the portion of the simulation code representing the subsystem with the Simulink subsystem itself. The close integration of the System Generator and MATLAB allows for this rapid validation. Upon the completion and validation of all the subsystems, the full system can be integrated and validated against the original simulation.

After the system is finished and verified in Simulink, it is then converted into VHDL using

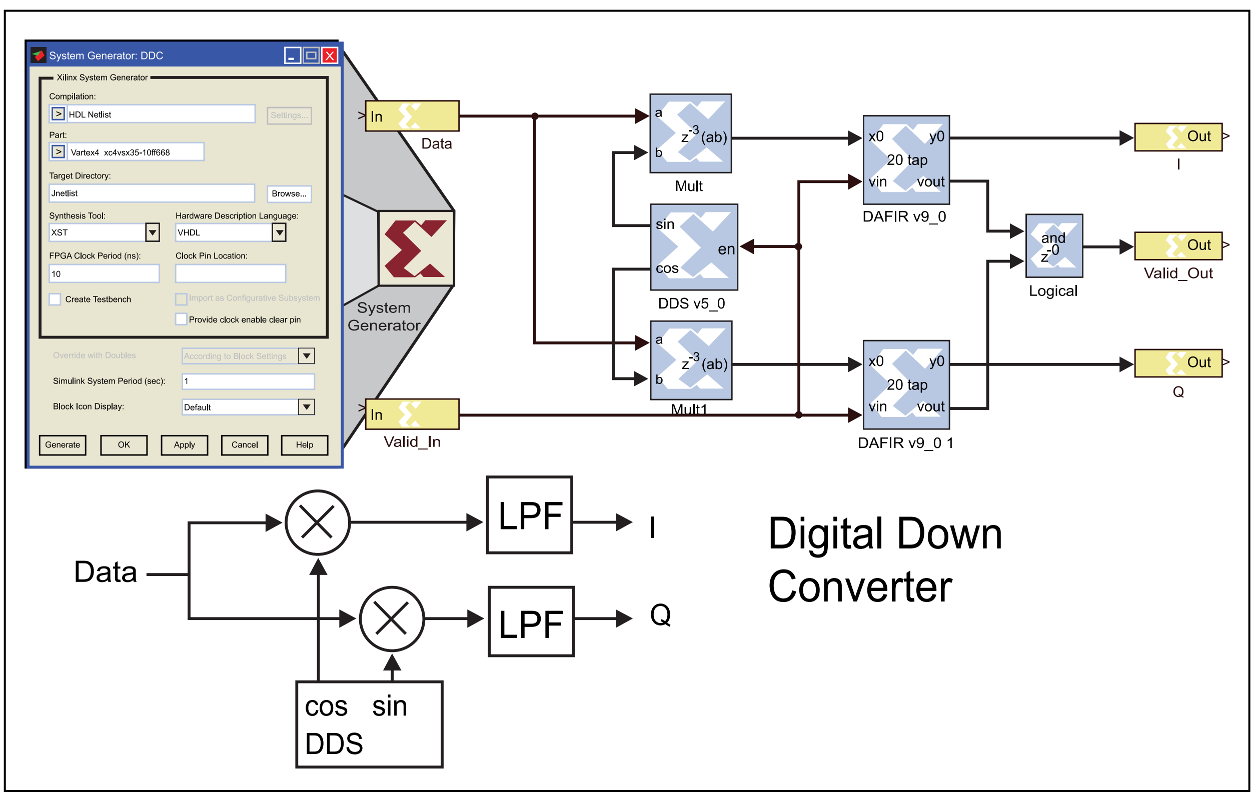


Figure 1. System Generator Design of a Digital Down Converter

the System Generator tool. The VHDL created is chip-specific to the part specified in the System Generator tool. This means that the code generated will work only on the specific Xilinx chip; however, it is highly optimized for that chip. The targeted chip can be changed and the code regenerated at any time, which helps to avoid obsolescence issues. Once the VHDL code is generated, some minor work is frequently required to integrate the System Generator portions of the design with the rest of the system. The System Generator design flow is shown in Figure 2.

The use of the System Generator has resulted in significant improvements in the development time of several systems and has enabled a much faster verification cycle for those systems. One of the systems developed using this tool was a signal processor for a low-power, low-cost frequency-modulated continuous-wave (FMCW) radar. A system block diagram of the radar signal processor is shown in Figure 3.

The initial system required approximately 2 weeks of development time to complete, with an additional 2 weeks of development time for the system modifications and refinements. The hardware used for the development was a low-cost development board from Xilinx shown in Figure 4; the output of the signal processor, displayed on an oscilloscope, is shown in Figure 5.

The use of the System Generator allowed for subsystems to be tested as they were developed by integrating them within a MATLAB simulation of the signal processor and comparing the results to the simulation alone. If the design were implemented using conventional FPGA design tools, it is estimated that the design process would have taken 6 to 8 weeks to achieve initial capability.

The primary benefit of using the System Generator is the rapid development time. With its close integration with MATLAB, much of the verification of the system can be done more quickly than if done in VHDL. The use of specific blocks to implement functions also results in efficient code optimized by the chip vendor for use on their hardware. The use of the System Generator shortens the development time of FPGA-based signal-processing algorithms significantly. On this project, development time was shortened by a factor of three, as compared to traditional design techniques, thus allowing systems to be more rapidly fielded and upgraded to meet the needs of the warfighter.

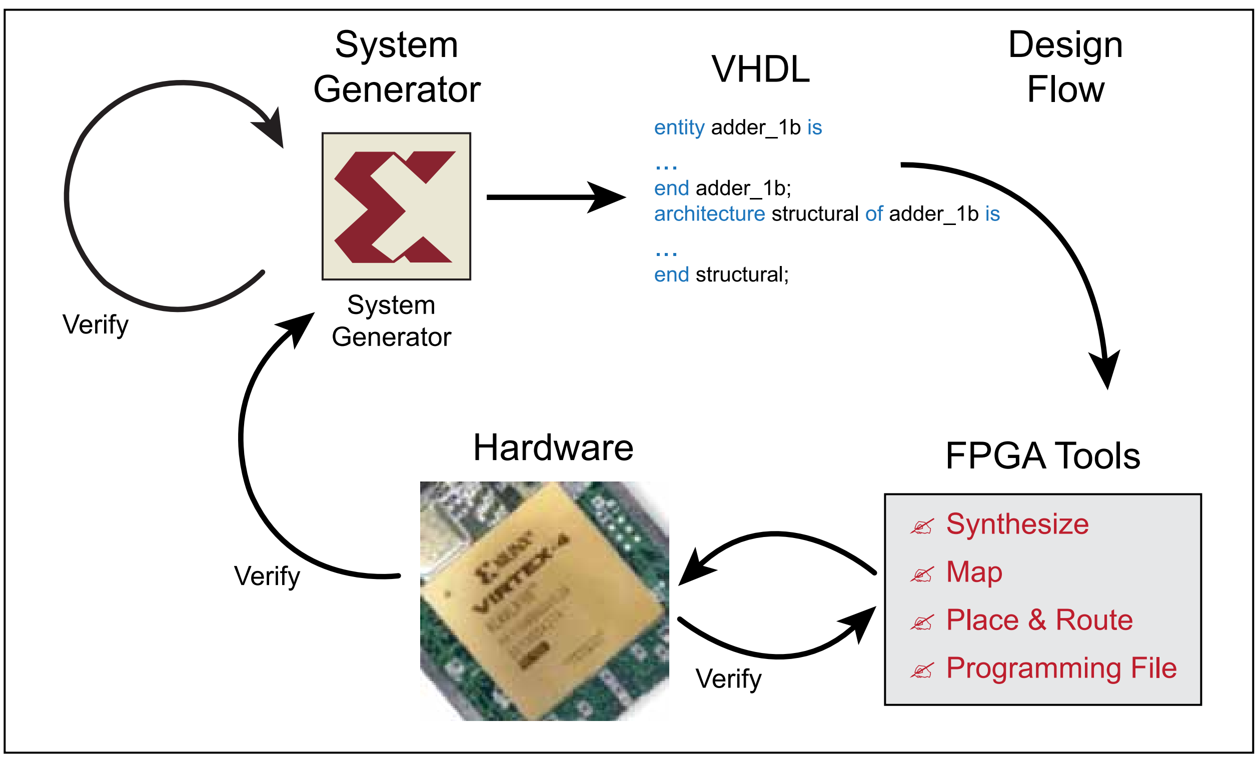


Figure 2. Design Flow Using System Generator

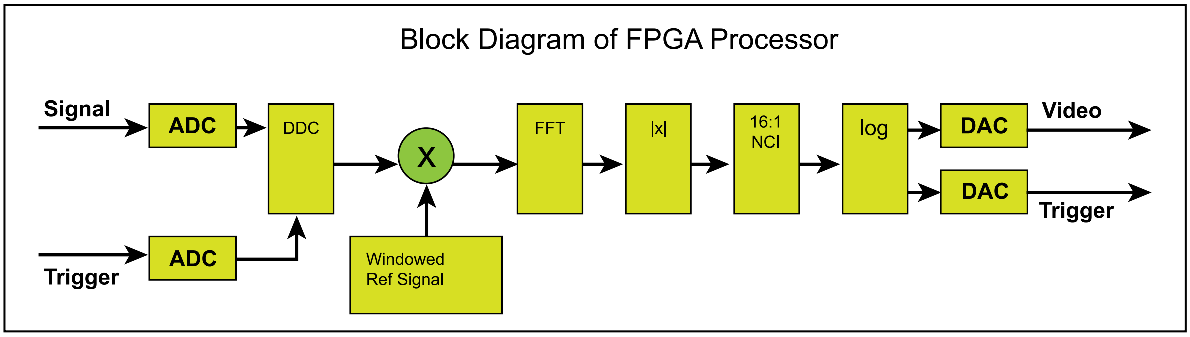


Figure 3. Block Diagram of FMCW Radar Signal Processor

Figure 4. Hardware Platform Used for the FMCW Radar Signal Processor

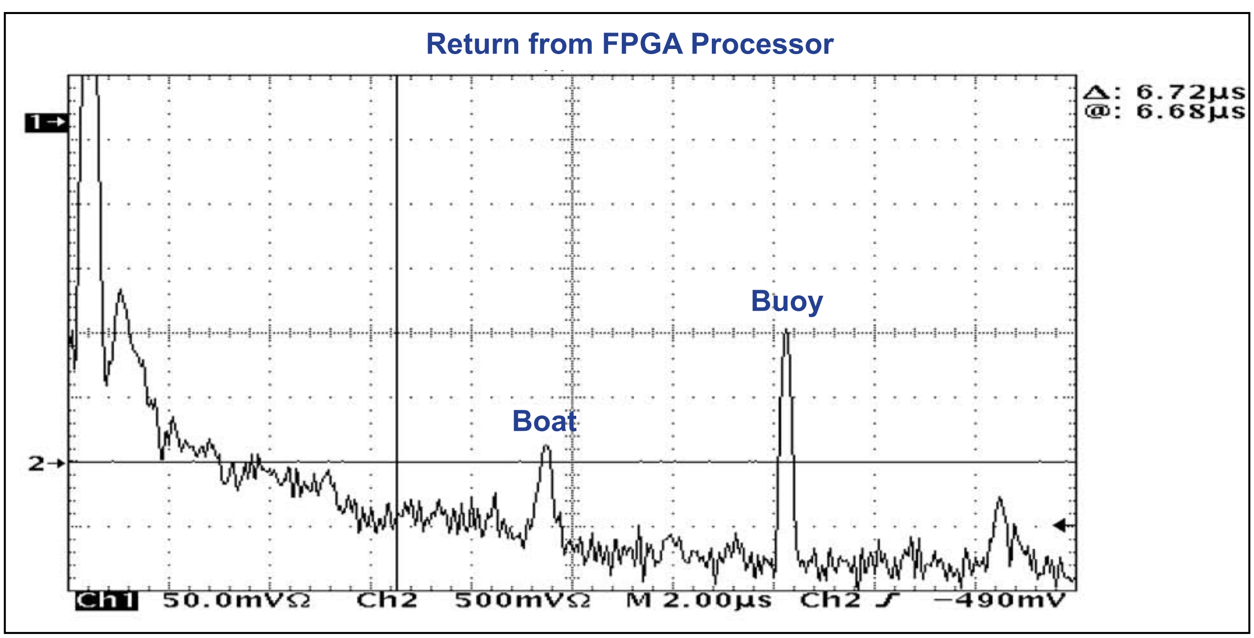


Figure 5. Radar Video Output of FMCW Radar Signal Processor

The AN/SPS-74 Periscope Detection Radar System

By Ian Barford, Mark Tadder, and Christopher Gorby

Over the last decade, the Navy's focus has increasingly shifted from open-ocean operations to littoral warfare. As the performance of the Navy's traditional antisubmarine warfare (ASW) sensors (passive and active sonar systems) degrades in the littoral environment, alternative ASW sensors, such as periscope detection radars, are required to provide effective ASW capability in these regions. In response to the U.S. Fleet Forces Command (USFFC) Integrated Priority Capabilities List (IPCL), a rapid-deployment capability periscope detection radar system program was initiated in August 2006. The AN/SPS-74 Radar System (see Figure 1) is currently undergoing test and evaluation at the Navy's Acoustic Test and Evaluation Center on Andros Island, Bahamas. It is also being installed in USS *George Washington* (CVN 73). This article describes the AN/SPS-74 periscope detection radar system program and provides an overview of the design features that permit the detection, discrimination, and declaration of periscopes in challenging environmental conditions.

Since the mid-1990s, the Navy has sought to develop a ship-based periscope detection capability. A developmental brassboard system has been periodically deployed and extensively tested since 1996 under the Office of Naval Research (ONR) Advanced Radar Periscope Detection & Discrimination (ARPDD) program. The ARPDD system consists of an AN/APS-137 airborne radar modified to interface with a developmental discrimination and post-processing computer system. After rigorous testing, it was determined that the experimental ARPDD system provided acceptable periscope detection and false-alarm rates. After receiving priority on the USFFC IPCL, an advanced technology demonstration (ATD) development effort was initiated by the Navy's Program Executive Office for Integrated Warfare Systems (PEO IWS). The AN/SPS-74(V) Rapid Development Capability (RDC) program was initiated in 2006 to develop and field an affordable, integrated radar and post-processing system that replicates the performance capability of the ARPDD system by porting ARPDD capability elements to an open-architecture (OA)/commercial off-the-shelf (COTS) environment.

The AN/SPS-74(V)1 Radar System, shown in Figure 2, is an X-band, narrow-beam, high scan rate, high processing capacity, periscope detection and discrimination radar that rapidly scans the sea surface over a full 360 degrees in azimuth. The radar's primary function is to provide periscope declarations to the shipboard

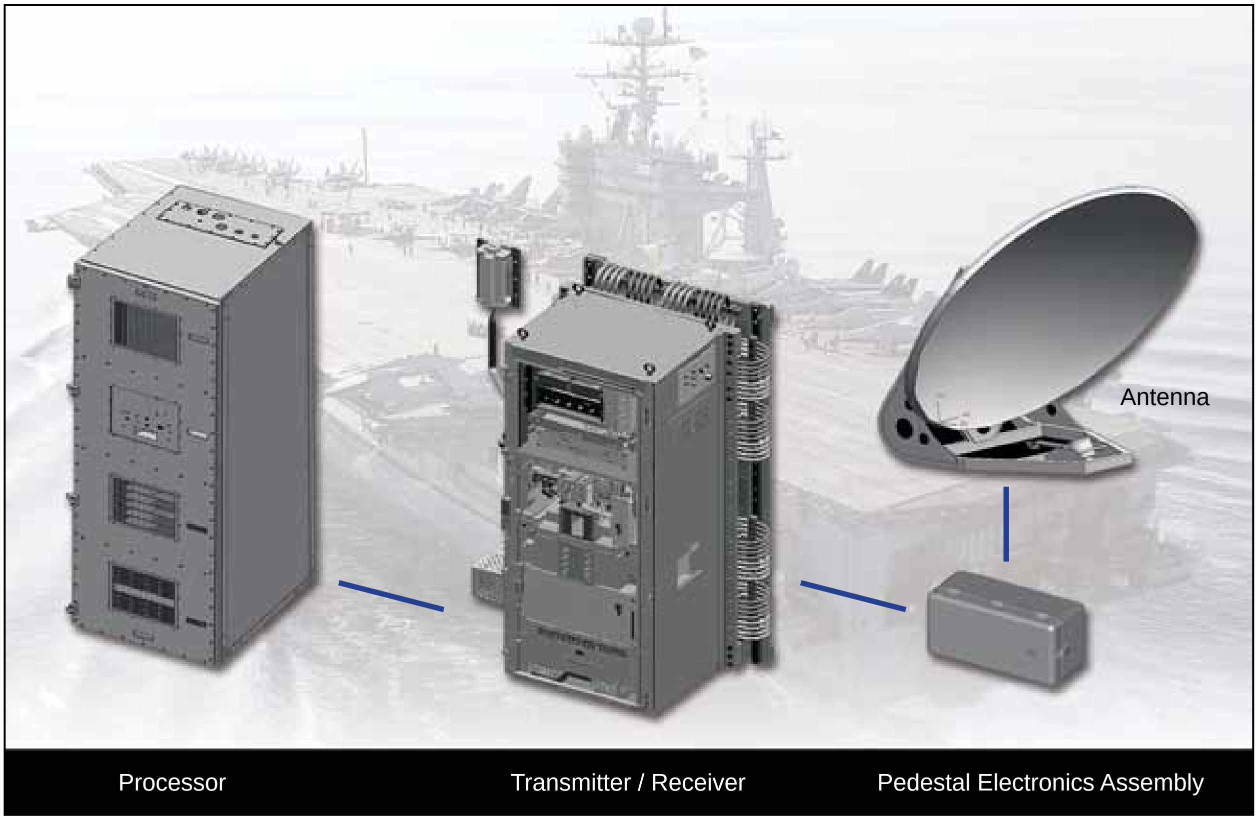


Figure 1. AN/SPS-74 Radar System

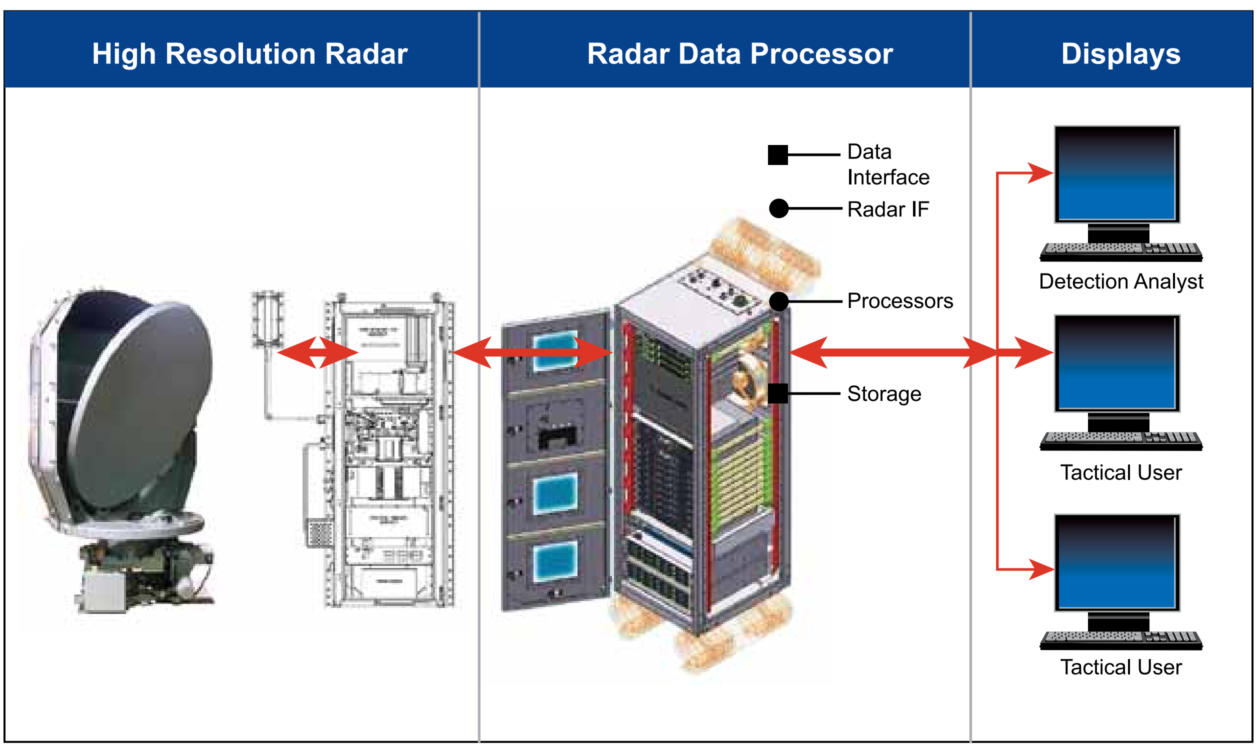


Figure 2. AN/SPS-74(V)1 Radar System

by detecting and discriminating periscopes in sea clutter. The system introduces a new high-resolution radar consisting of a modern ultra-wide bandwidth receiver, a high-reliability transmitter, and a 300-rpm scanning antenna. The radar data processor features very high throughput data processing using COTS processors.

Detection of periscopes is especially challenging since they are often hidden or obscured by ocean waves and because they may be exposed only for a short time. On every scan, the radar passes information to the high-performance data processor for immediate isolation of potential periscope targets from clutter. Using proven algorithms from the ARPDD program, the data processor processes potential periscope target data with a multifeature discriminator function and then provides automatic target alerts to the operator.

The radar digital display provides an ocean surface picture with rapid-classification aids that help the AN/SPS-74 radar operator make an informed decision regarding classification of detected targets as shown in Figure 3. The radar system is required to meet the challenging system specifications for the detection and classification of submarine periscopes. This system is required to unambiguously display any possible submarine periscope detection data while also displaying very little ocean-generated clutter return. Detecting and reporting false alerts is required to be kept to a minimum in all types of sea states.

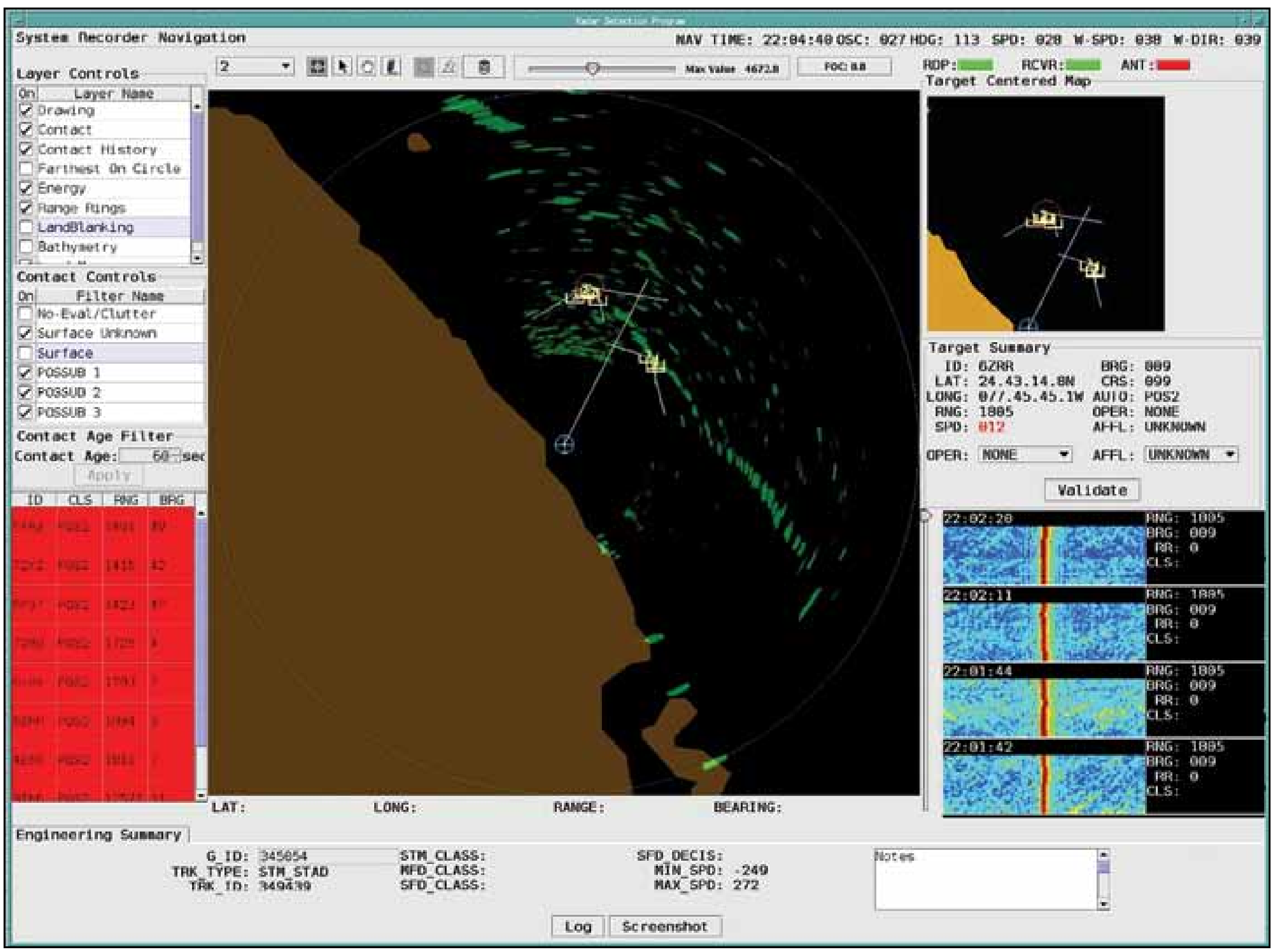
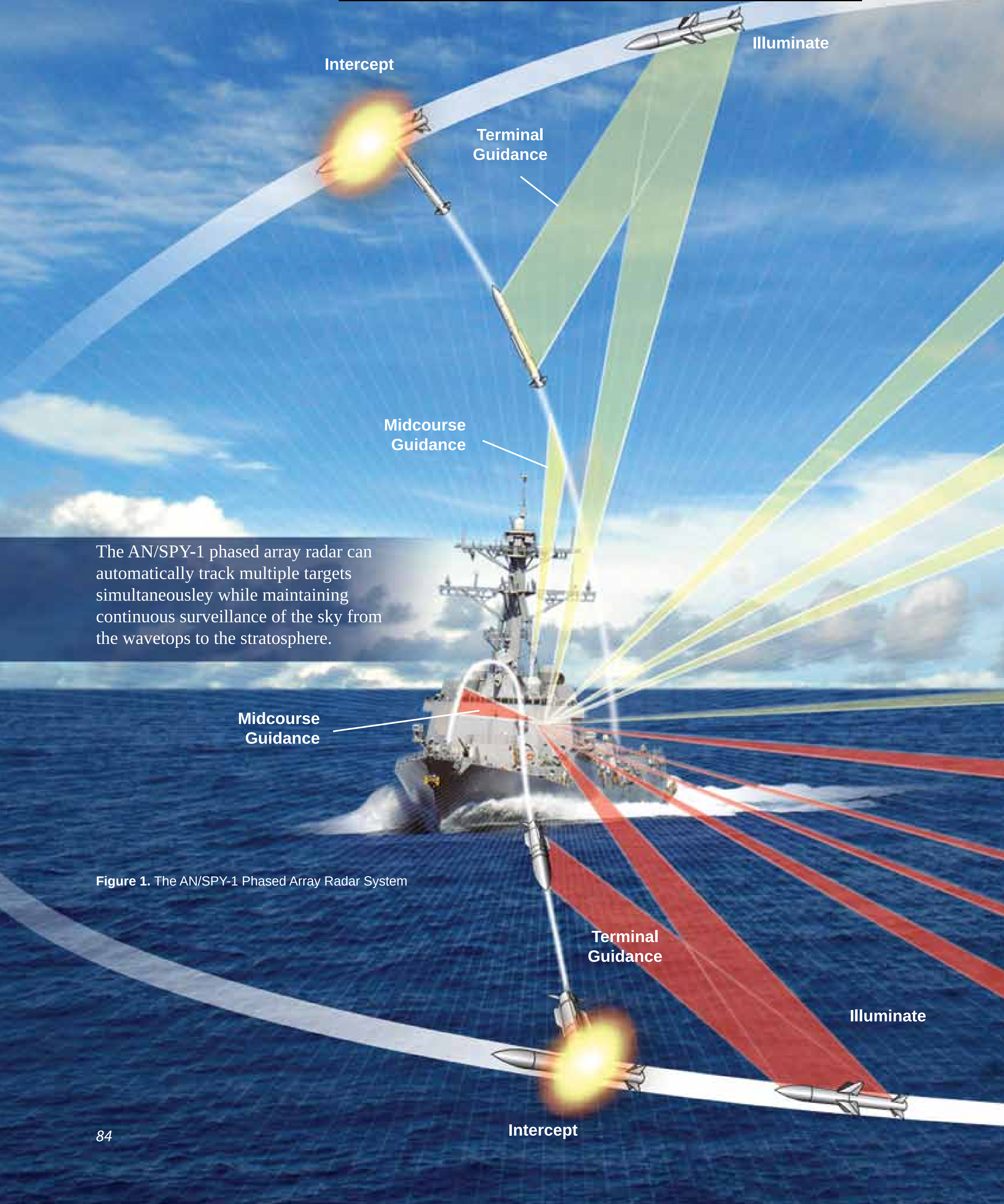


Figure 3. Periscope Detection and Discrimination Display

The AN/SPS-74 radar system is currently undergoing extensive test and evaluation at the Navy's Atlantic Undersea Test and Evaluation Center (AUTEC) on Andros Island in the Bahamas (see Figure 4). This location was chosen for its close proximity to deep water, which allows for submarines to enter and exit with ease. The antenna is installed on a platform at a height that is consistent with the intended installation location on aircraft carriers. Since April 2008, the AN/SPS-74 test team has conducted test events in which submarines and submarine-like targets have performed scripted mission scenarios. Using the data from these test events, radar engineers have optimized the system discrimination and classification parameters to meet the stringent system requirements.

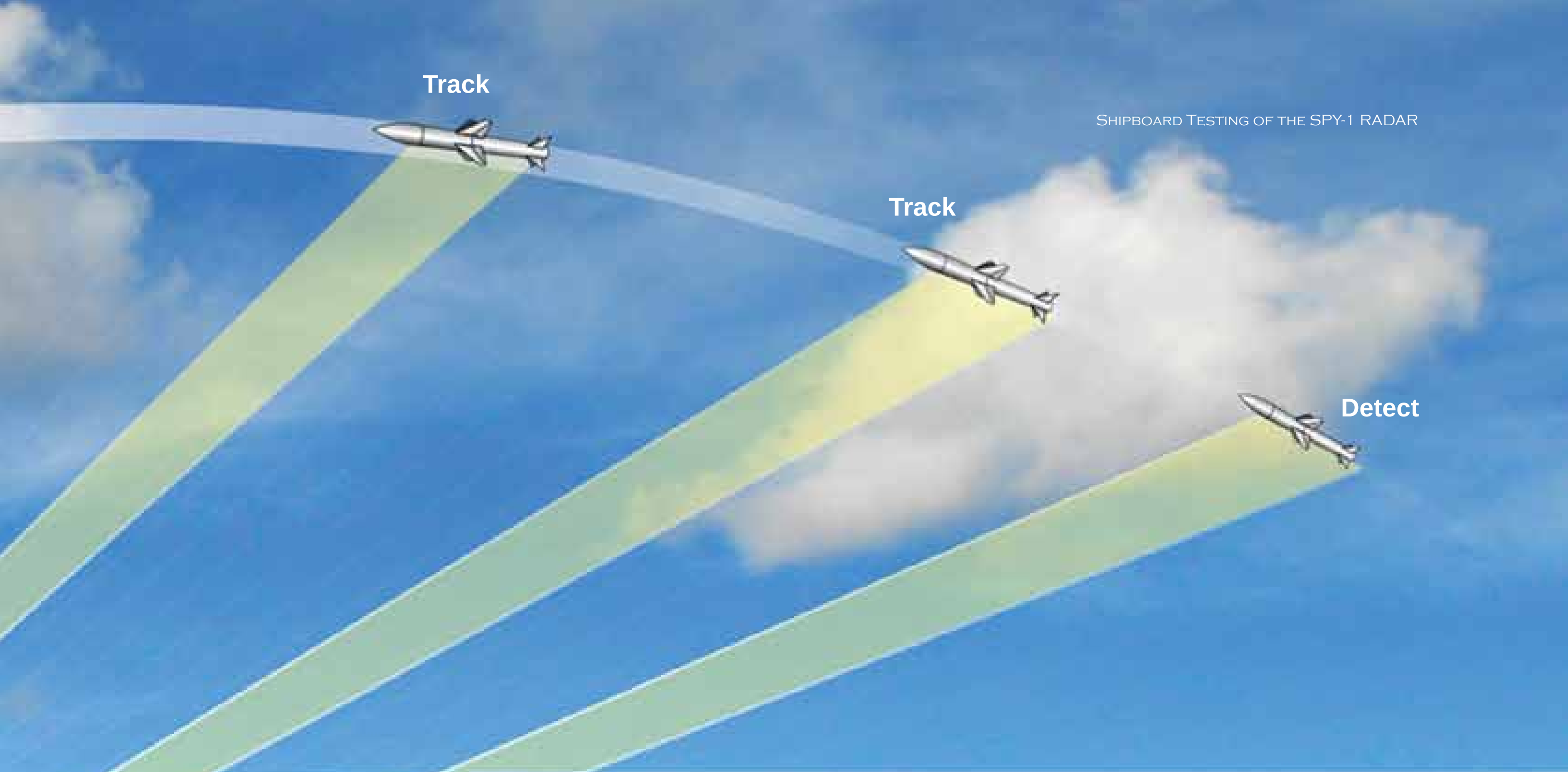
PEO-IWS plans to acquire eleven AN/SPS-74(V) systems, with ten systems slated for installation in U.S. Navy aircraft carriers and one system designated for installation at the Naval Surface Warfare Center (NSWC) land-based test site at Oceana Naval Air Station, Dam Neck Annex, Virginia Beach, Virginia. The system is also under consideration for future application aboard surface combatant ships. In support of the PEO-IWS, radar engineers from the NSWC Divisions at Dahlgren, Virginia; Port Hueneme, California; and Crane, Indiana have worked closely with the Naval Research Laboratory (NRL), Johns Hopkins University/Applied Physics Laboratory (JHU/APL), Northrop Grumman Corporation, and Three Phoenix Corporation to achieve program objectives.

Figure 4. AN/SPS-74 Radar Installation at the AUTEC Test Site



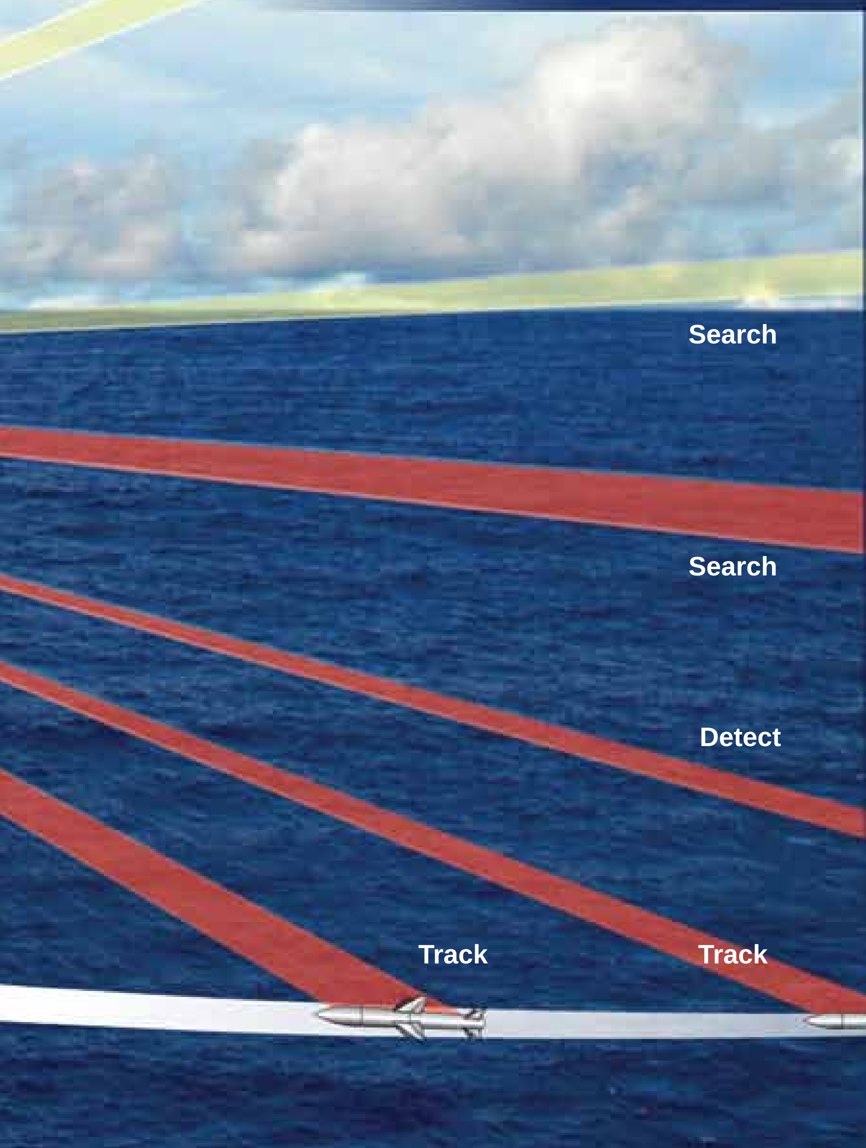
The AN/SPY-1 phased array radar can automatically track multiple targets simultaneousley while maintaining continuous surveillance of the sky from the wavetops to the stratosphere.

Figure 1. The AN/SPY-1 Phased Array Radar System



Shipboard Testing of the SPY-1 RADAR

By Randy Strock



Computer software testing and evaluation engineers might not have the most glamorous positions supporting the U.S. Navy, but their work is absolutely vital to warfighter and weapons system effectiveness.

Test and evaluation (T&E) is the key process that takes the computer programs of the Aegis Weapon System from the developmental stage to a completed, fielded system. The T&E process begins with unit testing of the developed code by the developer. It then moves on to element testing of the code against the Computer Program Requirements Specification (CPRS) and, ultimately, to system testing of the computer programs against the weapon system specification. While most of this testing can be performed in a laboratory setting, it eventually must be tested on board the ships where it will be used. This is important to the command and decision (C&D) and weapons control system (WCS) elements, but it is of vital importance to the SPY computer program. Only at sea, using real shipboard equipment in at-sea environments, can the SPY computer program be stressed to its limits. A depiction of the AN/SPY 1 Phased Array Radar System is shown in Figure 1 (see previous page).

In the 1990s, The Naval Surface Warfare Center (NSWC) Dahlgren was responsible for developing the Aegis Baseline 5.3.8 computer programs. Lessons learned from those previous baselines proved to software engineers that at-sea testing was critically important. Before then, after baseline development and testing was thought to be complete, the computer programs would go to sea. Once exposed to that environment, however, many more problems were found. Some problems were easily fixed, while others pointed to more deeply rooted design issues. Subsequently, with the Baseline 5.3.8 program, the Aegis philosophy of "build a little, test a little" was taken seriously and adopted by the SPY development team. From the beginning, during early development, the computer program was taken to sea as much as possible to wring out problems with the computer program code and transition data to support decisions on the next phase of development. NSWC Dahlgren was, and continues to be, in a unique position for this kind of work due to its close association with both the operational Navy and the developmental side of the Navy. The result of this at-sea testing approach yielded very successful computer programs that are currently fielded on 37 Aegis cruisers and destroyers.

In the early 2000s, Aegis Baseline 7 Phase I was under development by Lockheed Martin for the DDG 91 and follow ships. On these ships, the SPY-1D(V) radar was introduced. This third-generation SPY-1 signal processor brought several significant changes to the radar, including a large suite of clutter-canceling, moving-target indicator (MTI) waveforms. Designed and developed in the 1990s, this new radar suite had been extensively tested at land sites, including developmental testing (DT) and operational testing (OT) at the Combat System Engineering Development Site (CSEDS) in Moorestown, New Jersey, where Lockheed Martin is located. But it wasn't until 2003 that a ship was built with the radar installed.

NSWC Dahlgren engineers had been involved in virtually every phase of development and testing of the SPY-1D(V) radar system for the Navy. With the advent of the new radar signal processor and new computer programs to support it, it was strongly believed that at-sea testing was needed as soon as possible to ensure that the radar was giving the Navy the product that it required. NSWC Dahlgren engineers led the effort to go aboard USS *Pinckney* (DDG 91) while it was still in the Pascagoula Mississippi, shipyard in the summer and fall of 2003. They had prepared for at-sea testing as soon as the ship was put to sea. This effort led to the Navy executing an extended Alpha Trial, which contained over 34 hours of testing specifically for the SPY-1D(V) radar to test functions that were either impossible to test at land-based sites, or where the land-based data was insufficient. NSWC Dahlgren engineers were part of the team that developed the test procedures, performed the testing on the ship, and analyzed the data afterward. The results of this effort were very successful, in that many problems were found with the computer program that had been overlooked during land-based testing. These problems were then corrected in later builds of the computer program. Figure 2 shows the guided missile destroyer USS *Pinckney* (DDG 91).

Figure 2. The Guided-Missile Destroyer USS *Pinckney* (DDG 91)

The at-sea testing approach aboard USS *Pinckney* continued through the remainder of its shipbuilder trials and through its transit from Pascagoula to its home port in San Diego, California, in 2004. Many hours of specific testing were completed by the test team, as well as collecting and analyzing data from day-to-day operations. Problems continued to be found during this period and were fed back to Lockheed Martin to correct in later builds. By the summer of 2004, the team began to feel that the radar was going to be ready for its formal DT/OT testing in September.

As the developmental and operational test date approached, it became clear that the date was going to slip into 2005. USS *Halsey* (DDG 97) was targeted for testing in September of 2005, but budgets were tightening, and DT became one of the victims. Consequently, instead of a separate test event with its own test aircraft and missiles, DT was ordered to piggyback on the existing Combined Combat Systems Ship's Qualification Trials (CSSQTs) for the DDG 91 through DDG 95. NSWC Dahlgren was instrumental to the team that produced the development test plan and influenced the CSSQT testing to collect the data that was needed to test all the SPY-1D(V) functions called for in the Test and Evaluation Master Plan (TEMP). Over the next year, as testing progressed through the CSSQTs of the five ships, as before, more problems were found and fixed in the Baseline 7.1 computer program. By the time that USS *Halsey* completed the OT, the SPY-1 radar was ready. For the first time in the history of Aegis, the SPY radar was deemed "operationally effective." The guided-missile destroyer USS Halsey is shown in Figure 3.

During early- to mid-year 2000s, SPY computer program development shifted to an open architecture (OA) approach. This involved a complete rewrite of the computer program. Some design elements were brought forward from the preceding baselines, including 5.3.8 and 7.1, but the underlying structure of the program was rebuilt from the ground

Figure 3. The Guided-Missile Destroyer USS *Halsey* (DDG 97)

up. Testing at this time changed completely from the 1990s' approach. On the military UYK computers, the code was developed and compiled on a VAX computer and then had to be loaded onto the UYK computer in a special laboratory to be tested. The process was tedious and time-consuming, and laboratory time was limited. With the OA computer program, personal computers (PCs) had come along far enough that the SPY computer program could be written, compiled, and tested on a single desktop PC. Thus, the same computer program that was compiled and run on tactical computers on board ship could also be compiled and run on a PC. Using a PC, the program interfaced with the Testable Computing Environment (TCE) developed by Technology Services Corporation (TSC). This capability enabled developers to code and test computer programs 24 hours a day at their desks. This capability dramatically increased productivity and turnaround time, and decreased overall computer program error rates. However, desktop testing could never substitute for testing performed in the at-sea environment.

The earliest version of the SPY OA computer program that reached the stage where it could be tested on shipboard equipment was a version intended to be used with the SPY-1D(V) radar. NSWC Dahlgren was instrumental in getting this computer program to sea. Support included:

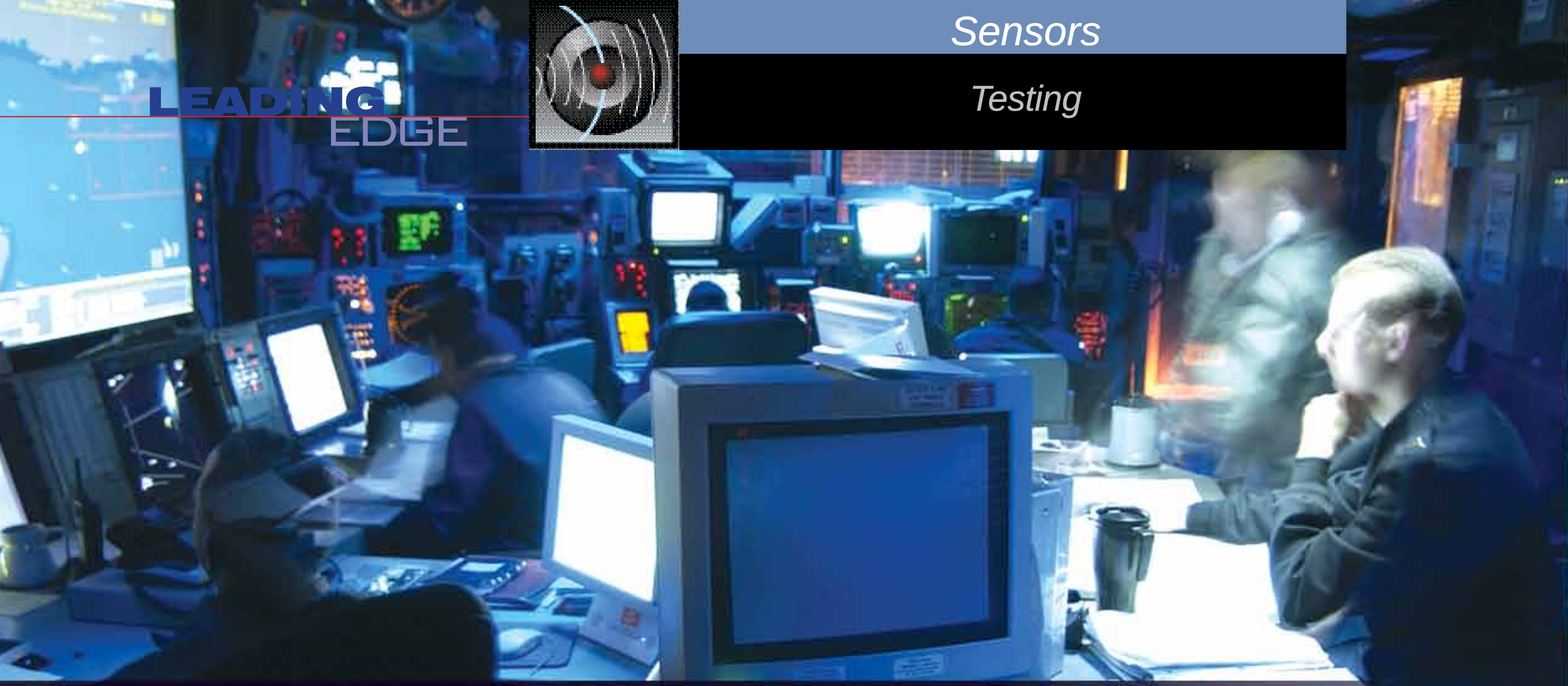
- Working with the ships to find test opportunities
- Developing the test equipment that went aboard the ships to interface with the shipboard computers
- Developing test procedures
- Participating in the onboard test events
- Analyzing the data during and after the events

As usual, the at-sea testing proved critical in the development of the SPY OA computer program. Many problems were found and corrected in the computer program thanks to the at-sea testing that was performed. Unfortunately, the SPY-1D(V) version of the SPY OA computer program was not put into service. However, since it was architected to be a superset computer program for all SPY-1 variants, it was taken as the basis for the Advanced Capability Build 2008 (ACB08) Cruiser Guided Modernization (CGM) computer program aboard Baseline 2 SPY-1A radar-equipped ships.

The ACB08 computer program was first made available to USS *Bunker Hill* (CG 52) in the fall of 2008. Once again, the SPY-1 engineering community took the initiative to get aboard the ship as soon as possible and collect data with the new computer program. Early testing in November and December 2008 focused on the simple basics of radar operation: search and track of targets of opportunity. Beginning in February 2009 and continuing through March 2009, more structured testing was accomplished. NSWC Dahlgren engineers were involved in the test planning for these events and supported the testing aboard the CG 52 for a total of 5 weeks during this period. Recorded data was received at Dahlgren after each test event and was analyzed in the weeks afterward. As learned many times before, at-sea data proved invaluable in providing an environment that simply cannot be replicated in a laboratory setting. Many additional computer program problems were discovered and corrected in later builds of the program as a result of this testing and analysis. USS *Bunker Hill* (CG 52) is shown in Figure 4.

Going into CSSQT of USS *Bunker Hill* (CG 52) and USS *Stockdale* (DDG 106) in June of 2009, at-sea testing of the SPY-1 radar continued. The CG 52 has the latest ACB08 computer program build, and the DDG 106 will be running with the Baseline 7.1R computer program. While weapon system problems are never desired, it is always better to discover them beforehand than to have ships deploy and go to war with them. Shipboard testing and evaluation of computer programs, therefore, really is vital to warfighter and weapons system effectiveness.

Figure 4. USS *Bunker Hill* (CG 52)



Integrated Electronic Warfare Test Facility

By Mark W. Karrick and Ronald D. Wood

The Integrated Electronic Warfare Test Facility opened in 2003 to enhance the Combat System Integration effort at the Naval Surface Warfare Center (NSWC) Dahlgren. The facility was built around the existing AN/SLQ-32(V) Electronic Warfare Reprogrammable Libraries (EWRL) mission, which provides mission updates to fleet electronic warfare databases and oversees the cyclic threat-database update process. The facility is used to lead the Navy's effort to upgrade aging shipboard electronic warfare systems and ensure that this critical warfighting data is integrated into the combat system while continuing to support the core EWRL mission. The Naval Surface Warfare Center, Dahlgren Division (NSWCDD) partnered with the Electronic Warfare Systems Project Office (PEO IWS-2E) and industry to meet the Navy's electronic warfare objectives through the Surface Electronic Warfare Improvement Program (SEWIP). SEWIP provides upgrades and new capabilities to the current AN/SLQ-32(V) electronic countermeasures system. A number of Integrated Electronic Warfare Test Facility projects are discussed as follows.

The Integrated Electronic Warfare Test Facility

The EWRL is involved in the development of electronic surveillance (ES) and electronic attack (EA) threat databases and active responses. The facility has a robust radar simulation capability in the Combat Electromagnetic Environment (CEESIM) and VARIgen simulators, which provide both live radio frequency (RF) and digital radar simulation inject (see Figures 1 and 2). Precise radar simulation is vital for accurate ES system identification and EA system response. The facility offers a unique site and equipment configuration. The core AN/SLQ-32(V) is divided in half, with the port side of the system inside the laboratory and the starboard side on an external tower. This allows for isolated testing on the port side and for detection of emitters of opportunity and live overwater and overland ES/EA testing from the starboard-side equipment.

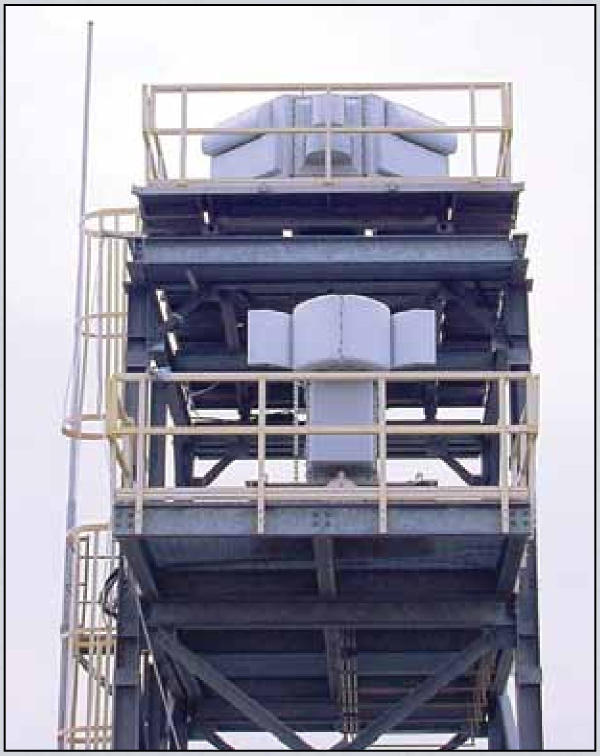


Figure 1. Integrated Electronic Warfare Test Facility AN/SLQ-32(V)5 Electronic Surveillance and Electronic Attack Antenna Tower

Figure 2. Radar Simulation and Generation Van

Surface Electronic Warfare Improvement Program (SEWIP)

SEWIP is a spiral development program for upgrading and providing new capabilities to the current AN/SLQ-32(V) electronic countermeasures system (see Figure 3). To date, the program has provided an upgraded open-architecture processor, a display console, and the addition of a specific emitter identification (SEI) capability. Future enhancements will involve adding a high-gain/high-sense receiver that will significantly improve the sensitivity of the SEWIP system. NSWCDD is the lead for threat database software testing for the SEWIP Program. The facility has the only shore-based connection between the SEWIP system and SIPRnet; NSWCDD used this unique singular link to development the U.S. Navy's AN/SLQ-32(V) Mission Planning website.

Common Display System/Common Processor System (CDS/CPS)

The CDS/CPS is the replacement for the fleet-standard Q70 display console. NSWCDD is researching the migration of the SEWIP Q70 software to the CDS/CPS platform for PEO IWS-2E as part of the Aegis Modernization Program. A prototype is shown in Figure 4.

Future considerations for this facility include connectivity to the Ship Self-Defense System (SSDS) at Wallops Island, Virginia. This would facilitate direct SSDS and AN/SLQ-32(V) threat database testing. Additional combat system integration with the Sea Air Integrated Laboratory (SAIL) at Patuxent Naval Air Station, Maryland, will provide integration with the AN/ALQ-142(V) and AN/ALQ-210(V) systems aboard the Light Airborne Multipurpose System (LAMPS) helicopter (see Figure 5). Integrating with SAIL will allow threat database analysts to upload ES system libraries to LAMPS platforms in real time. SSDS and SAIL integration will provide a more realistic and combat-system-representative testing environment to help keep the U.S. Navy on the forefront of electronic warfare and combat system integration.

Figure 3. AN/SLQ-32(V)5 Legacy and SEWIP Configuration

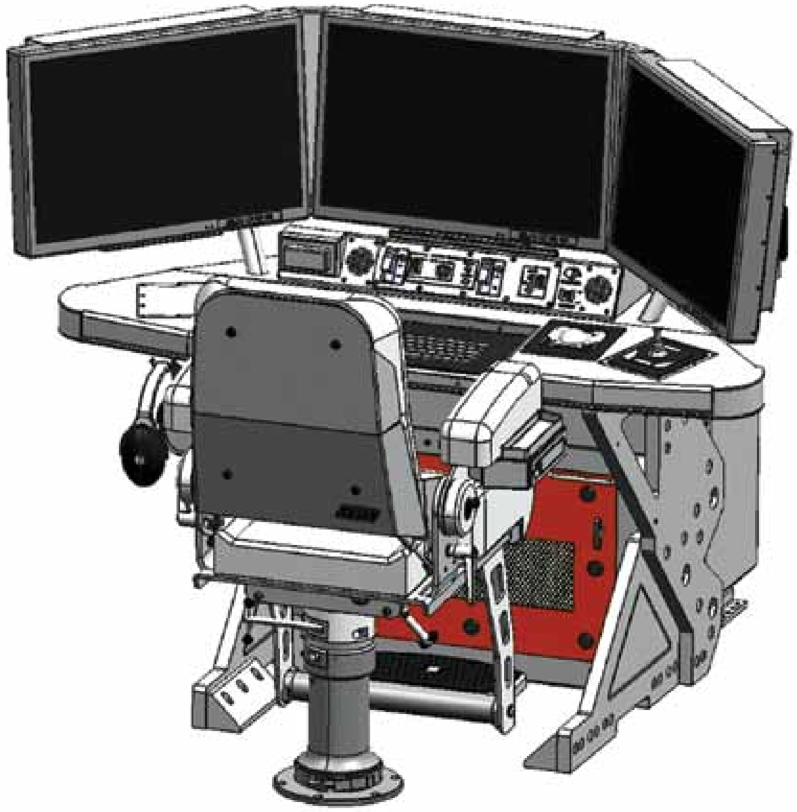


Figure 4. Prototype of the CDS/CPS Console

Figure 5. SH-60 LAMPS MK III Seahawk

Dual-Band Radar Program: Government and Industry Teamwork Wins the Day

By Brian Hill and David Scalia

Extraordinary events occur in the realm of test and evaluation. Sometimes the success of these efforts extends beyond tangible results and provides a glimpse of successful Naval Sea Systems Command (NAVSEA) Warfare Center government-contractor partnerships. The successful integration of the AN/SPY-3 Multifunction Radar (MFR) and the Volume Search Radar (VSR) Engineering Development models at the Naval Surface Warfare Center, Port Hueneme Division (NSWC PHD), while only one part of the overall test program for these radars, exemplifies how government and industry can partner together to achieve success despite seemingly insurmountable challenges.

The MFR and VSR constitute the Dual-Band Radar Program, a system of the DDG 1000 Program that operates in a full-service contract environment. It is within this environment that government and industry have nurtured a significant cultural change to combine, manage, and execute tasking. This effort led to a partnership among the Navy, prime contractors, and various support contractors that further led to increased responsiveness and adaptability to meet program executive office (PEO) requirements and contractual obligations. The end results have been a series of events successfully conducted and completed on schedule and within budget.

The government competitively awarded Raytheon Integrated Defense Systems a contract to produce the MFR Engineering Development Model in 1999, which underwent land-based testing at the Surface Combat Systems Center, Wallops Island, Virginia, through the end of 2005. The program of record was to conduct at-sea testing on a yet-to-be-determined platform. Northrop Grumman Ship Systems (NGSS), as lead integrator, selected the 563-ft, 9,200 ton, Self-Defense Test Ship (SDTS), ex-USS *Paul F. Foster* (DD 964) to serve as the at-sea platform. What followed was a 9-month, close-working partnership among Raytheon, NGSS, and NSWC PHD (our national team) to design the MFR installation for the SDTS (see Figure 1). Northrop Grumman utilized the local industrial base and NSWC PHD personnel via a Work For Private Parties agreement to make efficient use of the allocated budget.

Figure 1. AN/SPY-3 Multifunction Radar (MFR) Installed on SDTS

The SDTS, being a decommissioned Navy destroyer, was designed for operating complex Navy combat systems. The MFR, designed for use aboard DDG 1000, made various engineering challenges immediately apparent in order to adapt the system for the SDTS. For example:

- The SDTS had no physical location to hold the 25,500-lb array enclosure at the proper height, so a tower was designed and constructed pierside (see Figures 2 through 4). This necessitated other studies to be performed, including weight and moment analyses.

Figure 2. MFR Tower Being Installed on SDTS

- The SDTS had sufficient power for the MFR installation; however, distribution became an issue. The load had to be balanced from multiple load centers while accounting for the ramp rate and other power factors.
- The SDTS chilled water system had to be modified and augmented to allow sufficient cooling of the MFR.

Other challenges included various security requirements, resource sharing with other systems installed aboard the SDTS, and corrosion concerns related to operating a temporary installation in a corrosive saltwater environment.

These challenges were in addition to the normal approvals that surround installing and operating a system, such as frequency approvals, site approvals, adherence to National Environmental Protection Act requirements, and for this particular effort, coordination with the California Coastal Commission. The national team was able to complete the entire installation without mishap within the time and budget allocated. The result was the successful completion of the MFR at-sea test (DTB2-410) in the scheduled four underway periods via a collaborative Raytheon and government test team. At the conclusion of the at-sea testing, the MFR was scheduled for installation in a newly constructed building, the Wallops Island Engineering Test Center (WIETC), where it would be integrated with the VSR. Construction delays moved the building completion date, which required the MFR to remain installed on the SDTS. This allowed the MFR test team to continue testing, leveraging off of other programs and their test events.

Figure 3. MFR Antenna Shelter Being Mounted on Tower Onboard SDTS

Figure 4. MFR Signal-Processing Enclosure Being Installed on SDTS

An engineering challenge arose when the leverage test events required the SDTS be operated without personnel on board. The SDTS has been modified to allow full remote control of the entire ship, including all permanently installed combat systems; so for the primary systems, this requirement was already met. The MFR, however, was never intended to be remotely controlled. Once again a partnership between Raytheon and NSWC PHD engineered a solution, modifying portions of the hardware and software to allow the MFR to be remotely controlled while meeting all safety and security requirements. Challenges again arose with respect to ensuring that interference from the MFR would not cause unintended consequences for the primary system undergoing test. Raytheon and the MFR test team had to work closely with the subject matter experts for each of the various systems to test and validate that there were no issues. Ultimately, MFR participated in an additional 2 years of testing aboard the SDTS. This feat was possible only due to national team collaboration across government and industry.

Volume Search Radar (VSR)

The VSR's path to NSWC PHD brought a new set of engineering challenges for the government and industry team. Raytheon was awarded a contract to develop and build the VSR array with Lockheed Martin Maritime Systems and Sensors. The plan of record was that after completion of the VSR array near-field testing at the Lockheed Martin facility in Moorestown, New Jersey—which was scheduled for completion at the end of May 2007—the VSR was to be installed in the newly constructed WIETC. Once installed, the VSR would undergo initial high-power testing and technical performance measurement (TPM) verifications prior to the start of integration with MFR. These initial tests were required by NAVSEA Program Executive Office Ships (PMS 500) and Program Executive Office Integrated Warfare Systems (PEO IWS 2.0) (responsible for ship construction and radars, respectively) to make a decision on whether or not to proceed with VSR production. However, the delays that prevented the removal of the MFR from the SDTS also affected the VSR, and it became apparent to both program offices that this testing was in jeopardy of not meeting the schedule. To maintain the program-of-record schedule, a study was commissioned in August 2006 to determine the feasibility of performing the initial testing at an alternate test site until WIETC construction was completed.

The Radar Suite Acquisition Team subsequently determined that the Surface Warfare Engineering Facility (SWEF)—a five-story, 50,000-sq ft, oceanfront, land-based test site, located at NSWC PHD—met the criteria for performing the initial testing. Faced with exacting time, funding, and resource constraints, the government and industry team convened to boldly orchestrate an unparalleled set of actions that accomplished the installation goal within a 4-month time frame. The effort enabled the VSR to conduct 5 months of extensive far-field integration and TPM verification that included high-power radio frequency (RF), system alignment, antenna patterns, and accuracy measurements.

As with the MFR installation and test effort, the government and industry team partnership included NAVSEA and Raytheon, with the addition of Lockheed Martin, as well as local southern California industrial support. Concerning the major challenges for this project, some efforts remained in the government's purview—namely, environmental and site approvals (working with the California Coastal Commission), along with a concentrated contracting authority effort to modify various contract vehicles to enable what was an essentially unplanned event.

Figure 5. SPY-1A Array Being Uninstalled from the SWEF

The engineering challenge involved removing an existing AN/SPY-1A radar suite and reconfiguring the building infrastructure to support the VSR (see Figures 5 through 8). Since all existing installation drawings were designed for a WIETC installation, considerable effort was required concerning design and technical specifications before installation drawings could be produced. Additionally, due to the intended temporary nature of the project, a concentrated effort was made to keep cost as low as possible by utilizing equipment and plans already on hand and by holding infrastructure changes to the SWEF to a minimum.

The overall endeavor had several unique challenges that were overcome or mitigated by exemplary engineering practices. One recurring challenge was that many of the contributing events had never been attempted before with the VSR. These challenges included:

- The VSR's installation specifications had to be adjusted because they were derived from the final ship design, where the radar needed to be installed into a composite superstructure with the array and load-bearing structure, unlike the SWEF installation.
- The VSR system had never been installed and connected end-to-end, let alone lifted and placed into a full mounting surface or attached to the exterior of a building.
- Installation required lifting the array with a nonexistent lift fixture that would support 14 tons and allow the array to be tilted back to a 20-deg angle.

There was an exact requirement for the flatness of the array face after installation across the 16-ft array face. The plan was to use adjustable shims for each mounting hole. This provided the capacity to alleviate some of the flatness margin to counter what turned out to be an out-of-tolerance foundation due mostly to lesser criteria when the building was constructed and the SPY-1A array installed. A series of machined aluminum leveling plates were designed that allowed the foundation to maintain the flatness required.

VSR had the same requirements for environmental and site approval as the MFR; however, due to the location of the SWEF—within 100 yards of a public beach—and due to the compressed schedule, a more concerted effort was required. Community leaders were engaged and briefed, as were key representatives from all affiliated groups to ensure that all community concerns were addressed up-front.

Figure 6. The Original Octagonal SPY-IA Opening Was Made Rectangular to Accommodate the VSR

Figure 7. VSR Being Installed at the SWEF

The most difficult challenge to overcome was one that provided the most important lesson—that even a tight schedule should not trump best engineering practices. The initial design of the secondary cooling loop consisted of stainless-steel piping of various diameters and specified using flange joints in the construction to reduce the complexity and construction timeline. This proved to be an error in the design. Excessive flexing of the cooling system due to the high rate of flow and pressure required to cool all of the equipment led to continual leaks at all flange mating surfaces despite various efforts to correct this defect. Faced with this issue, the team's engineering decision sacrificed 3 weeks of the project schedule by replacing all flanges with butt welds. Schedule impact was ultimately mitigated by resequencing other start-up test events (i.e., lighting off and testing the IBM mainframe computers). Consequently, the team was able to alleviate the impact to the overall schedule, and as a result of the partnership, Raytheon was able to conduct over 5 months of high-power testing and confirm that key performance parameters were being met.

Win-Win-Win Situation

The culmination of an incredible amount of coordination across the government and industry is a testament to the dedicated professionalism of all those involved. The success of the Dual-Band Radar Engineering Development Models Project at NSWC PHD demonstrated the team's ability to put cultural differences aside and focus on the common goal of advancing the programs along their acquisition paths in support of the DDG 1000 Program. The result—government and industry teamwork wins the day, and Navy warfighters gain enhanced radar capabilities.

Acknowledgments

Steve Alkov and Lawana Godwin (CACI, Inc.) contributed to this article.

Figure 8. SWEF with the VSR Installed

AN/SPY-1B/D Radar Design Changes Supporting Aegis Ballistic Missile Defense

By Bernard Ulfers and George LeFurjah

The Aegis Combat System is an integrated system supporting warfare on several fronts—air, surface, subsurface, and strike—and the Naval Surface Warfare Center, Dahlgren Division (NSWCDD) has been intimately involved in the development, test, certification, and fielding of almost every new baseline of the Aegis Weapon System (AWS) since the 1970s. This involvement continues as the AWS evolves into a critical element of the Ballistic Missile Defense System (BMDS). The Antiair Warfare (AAW) components of the AWS are the AN/SPY-1B-/D radar system, the Command and Decision System, and the Weapons Control System.

Ballistic Missile Defense System (BMDS)

The BMDS is a system of systems employing a layered defense architecture. It consists of several systems (or elements) at each layer, allowing for multiple engagement opportunities against ballistic missiles (BMs) before they reach their intended targets. BMs follow three flight phases: boost (preburnout), midcourse (exoatmospheric), and terminal (post-reentry). Currently, interceptors and associated sensor systems have been deployed to engage BMs in their midcourse and terminal flight phases. For instance, the Ground-Based Midcourse Defense element is deployed in Alaska and California to defend against Intercontinental Ballistic Missiles (ICBM) and long-range BMs during their midcourse phase flight. The AWS sea-based midcourse element is deployed to defend against short- and medium-range BMs during their midcourse flight phase. Detection, tracking, and discrimination of lethal objects by the associated sensors allow the interceptors to utilize hit-to-kill technology against the threat while in the exoatmosphere. The terminal phase is the last opportunity to engage the threat. Two elements providing this terminal capability are the Theater High-Altitude Area Defense (THAAD) and the U.S. Army Patriot Advanced Capability (PAD-3) systems. Figure 1 depicts BM flight phases.

Aegis Ballistic Missile Defense (ABMD) was initially fielded as the 3.6.1 AWS baseline to provide autonomous (search, track, engage, and kill) BM defense against short- and medium-range threats and, to provide surveillance support (search, track, and hand-off) to other elements for a mix of short-, medium-, and some long-range threats. The next upgrade to be deployed, the ABMD 4.0.1 baseline, enhances capability against short- and medium-range threats, from unitary to complex separating. In addition to surveillance support to other elements, ABMD 4.0.1 is also capable of launching

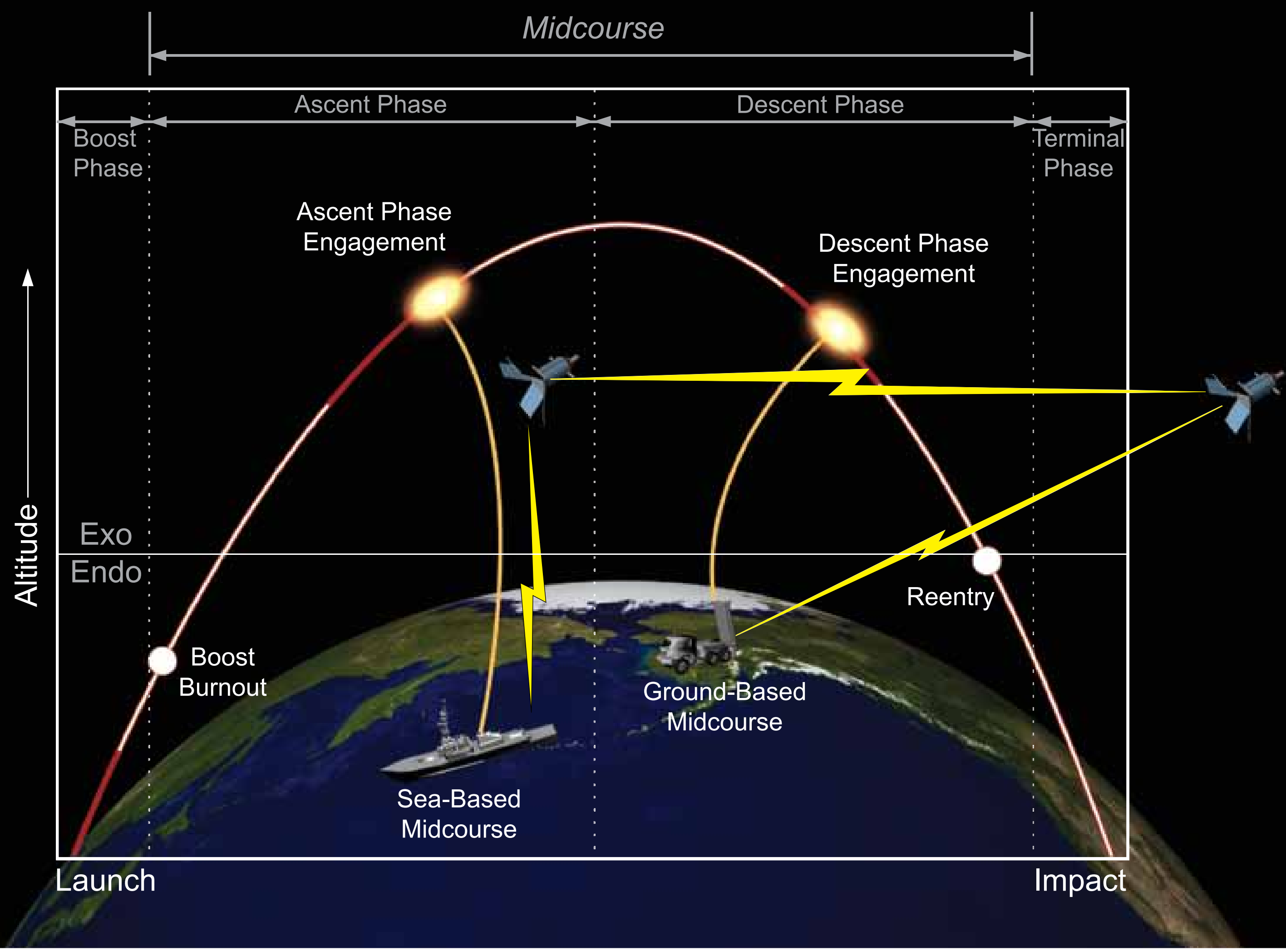


Figure 1. Ballistic Missile Flight Phases

interceptors using external, or remote, BM tracks (launch on remote).

The next ABMD Weapon System (ABMD 5.0) will transition the AAW and ballistic missile defense (BMD) functionality from the older control computers to new commercial off-the-shelf (COTS)-based computers allowing for a single computing system to perform BMD and AAW missions jointly. ABMD 5.0 also brings into play the newly developed Multimission Signal Processor, which combines the receiver and signal processing functions supporting AAW and BMD waveforms together within one set of cabinets.

The AWS was not originally designed with BMs in mind. Designed during the Cold War, it was intended to provide protection from cruise missiles and aircraft for groups of combat vessels in blue-water environments. The system's primary sensor, the AN/SPY-1A radar, provided long-range search and track coverage. As threats evolved and the international scene changed, the AWS evolved as well. In the 1980s, AN/SPY-1B/D radar improvements included higher duty-cycle transmitters, antennas with better sidelobes, increased subclutter visibility, and better environmental controls. This was primarily to counter electronic attack threats and reduce background clutter. In the 1990s, the AN/SPY-1D(V) radar provided substantially more subclutter visibility, increasing detection and track performance against low-flying cruise missiles hidden in sea clutter and near high-clutter littoral environments. Changes were also made to counter more sophisticated electronic attack threats. Since 2000, as part of the BMDS, ABMD capabilities have expanded to include defense against BM threats. The ABMD Baseline 4.0.1 SPY-1 radar introduces new waveforms, signal processing, tracking, and radio-frequency discrimination functionality.

As BM threats become more advanced, the AWS adapts. Complex, separating threats typically break up into numerous objects. Some of these threats may deploy countermeasures. To properly discriminate lethal objects from nonlethal objects associated with the BM launch event, kinetic data obtained from object tracks—as well as data from infrared (IR) images and radio frequency (RF) images—are used. To reduce radar loading, the ABMD 4.0.1 employs single-beam, multi-object tracking. This increases the number of objects that can be tracked simultaneously using only one radar beam (or dwell). ABMD 4.0.1 also adds a new set of radar waveforms, along with advanced digital signal processing. This allows the radar to synthetically combine many pulses in order to construct a synthetic wideband RF image with higher range and higher Doppler resolution than was possible with the previous baseline.

At the heart of the AWS is the AN/SPY-1B/D radar. The radar consists of transmitter, antenna, receiver, signal processor/waveform generator (WFG), and computer control components. In ABMD 4.0.1, these components are augmented with an adjunct signal processor known as the BMD Signal Processor (BSP) (see Figure 2). The BSP comprises a new WFG, receiver, digital signal processor (DSP), and control computer. These new components are integrated into the existing components to provide bursts of the new radar pulses, along with special processing suited for tracking and discriminating BM objects.

Design and development challenges include the careful scheduling and timing of successive radar beams using the new waveform bursts, along with the legacy waveform pulses. Land clutter and electromagnetic interference (EMI) found in the operational environment continue to pose design challenges as well. Another challenge facing ABMD 4.0.1 is determining the period of time that radar system calibration will hold.

Aegis BMD Program Office Support

During the design and development of the adjunct BSP, the ABMD Program Office established a Joint Navy/Lockheed-Martin Radar Integrated Product Team (IPT) comprising organizations including:

- Naval Research Laboratory
- NSWC Port Hueneme Division
- John Hopkins University Applied Physics Laboratory
- Technology Services Corporation
- Massachusetts Institute of Technology (MIT) Lincoln Laboratory
- System Engineering Group

The IPT was intended to cooperatively and jointly explore design solutions, such as the mitigation of EMI effects, mitigation of land-clutter effects, optimization of sidelobe blanking algorithms, and assessment of different RF features as discriminants. NSWCDD provided Navy oversight and expertise in co-leading the IPT. NSWCDD

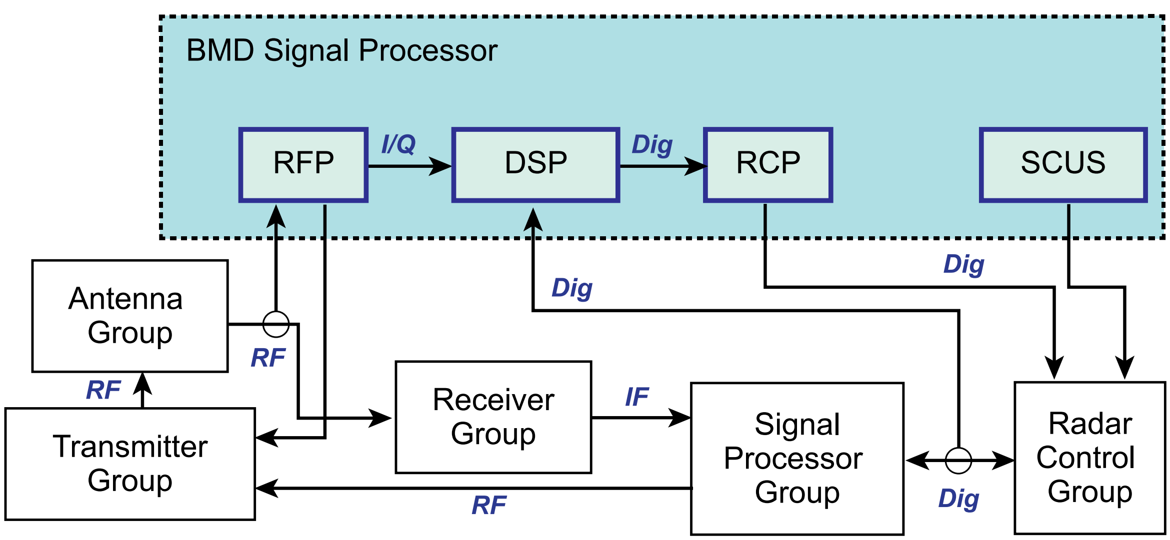


Figure 2. AN/SPY-1B/D Radar System Augmented with the BMD Signal Processor

also provided support to the ABMD Program Office, managing reviews of specifications as part of the design review process. Today, NSWCDD continues to exercise a leadership role in the joint Radar IPT for ABMD 4.0.1 and the follow-on baseline, ABMD 5.0.

NSWC Radar Clutter Modeling

Engineers at NSWCDD are involved in the ABMD 4.0.1 Program radar development process from generation of radar requirements to design to verification to certification. Clutter modeling results produced by the in-house, site-specific radar clutter model—the Littoral Clutter Model (LCM)—were instrumental in driving system requirements for clutter mapping, detection, and mitigation algorithms, as well as sidelobe blanking algorithms. NSWCDD engineers also provided significant technical support in the detailed design and verification of these algorithms.

The LCM is a site-specific simulation of the backscatter from both land and sea for a ship-based radar in a littoral environment, in the presence of ducting. The inputs to the model include:

- Geographic location of the sensor
- Maximum range and angular width of the azimuth sector over which the radar is to transmit
- Radar parameters, such as frequency, antenna height, beamwidth, and elevation angles

In order to evaluate the effect of atmosphere and the sea surface on both propagation and clutter, estimates of the atmospheric refractivity over the region and the sea state are also used as inputs. The principal output from the model is simulated clutter power along each azimuth in the propagation sector, which may be plotted as the Plan Position Indicator (PPI) display of a clutter map.

To simulate the diffraction and shadowing of a clutter patch over variable-height, site-specific terrain, a parabolic wave equation model is executed with terrain contours from Digital Terrain Elevation Data (DTED) files provided by National Geospatial-Intelligence Agency (NGA). The United States Geological Survey (USGS) provides a global land-cover database, Advanced Very High Resolution Radiometer (AVHRR), with 24 terrain type classifications, along with a latitude and longitude worldwide reference. The terrain types are correlated with the DTED data to associate appropriate electrical properties and surface roughness values with each patch of terrain. With the terrain heights, electrical properties, surface roughness, and atmospheric refractivity as inputs, the PWE Model is able to compute a propagation factor for each clutter patch along each propagation path. In order to model backscatter from patches of terrain or ocean surface, the Navy-Standard Georgia Institute of Technology (GIT) sea-clutter model is employed. For land clutter, the Low-Angle Radar Empirical Land Clutter Model designed by J. Barrie Billingsley at MIT Lincoln Laboratory is employed.

NSWC Radar Calibration Test Support

Verification of radar system calibration at the land-based test site in Moorestown, New Jersey, presented system engineers and the ABMD program office with unique challenges. Calibration of the new BSP waveform bursts through the radar equipment must be performed periodically by capturing radar returns from a balloon-borne machined calibration sphere away from sea or land clutter. These returns are then tuned to optimize image-processing performance. To completely capture the responses of the whole radar system is a time-consuming process. It is, therefore, in the best interests of the operational Navy for the designers to reduce the number of these sphere track events to once per 6-month period. Verifying that such a calibration event produces good performance consistently over a long period of time requires a repeatable test with good controls on the test environment. A solution was proposed by NSWCDD engineers to provide and man a tethered aerostat system equipped with a radar sphere target attached to the tether near the land-based test facility, the Combat System Engineering Development Center (CSEDS) in Moorestown, New Jersey. NSWCDD engineers from the Potomac River Test Range Branch have supported similar tests for many years and are currently supporting this effort over a 9-month test period. Figure 3 shows photographs of an Aerostat Test.

As the AN/SPY-1B/D radar evolves to meet ABMD requirements, engineers at the Naval Surface Warfare Center (NSWC) Dahlgren will continue to support the evolution of the ABMD Program. As a result, our Navy and our nation will continually remain well postured to defend against BM threats.

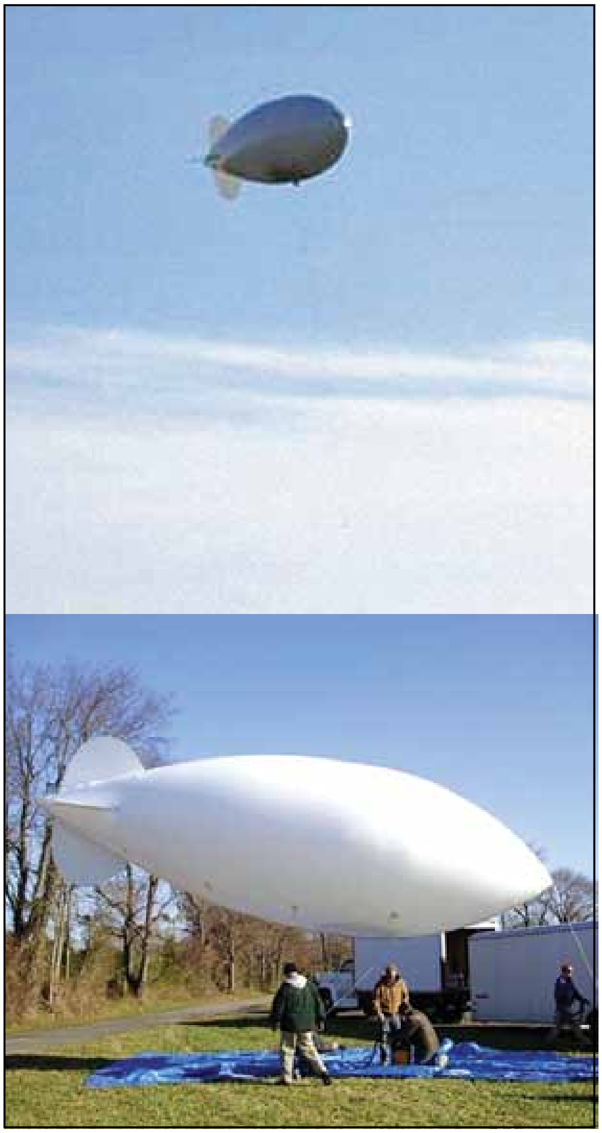


Figure 3. Aerostat Test, Rancocas State Park, New Jersey, 2 December 2008

The AN/SPS-48G Radar System Sustainability Upgrade

By Daniel Quigley, Lance Walters, Caitlin McInnes, and Christopher Gorby

The AN/SPS-48 radar system provides three-dimensional air surveillance for U.S. Navy aircraft carriers, amphibious assault ships, and amphibious dock landing ships. Its mission is to provide air defense surveillance, support air traffic control, supply accurate target coordinate data for weapon queuing, and support combat air patrol aircraft operations during peacetime and in war. The current version of the AN/SPS-48 radar, the AN/SPS-48E, has been in service in the U.S. Navy since 1987 and is expected to remain in service beyond 2030. In order to ensure that the readiness and rapid-response capabilities of the U.S. Navy remain intact, the SPS-48G Radar Obsolescence Availability Recovery (ROAR) program was initiated. The ROAR program is responding to a need for improvement of declining reliability, maintainability, and supportability issues. This article describes how these issues are addressed via an open architecture (OA)-based system redesign that leverages new technology and by the addition of a new embedded training and system-support methodology.

Introduction

For over a decade, the AN/SPS-48E radar has experienced a decline in reliability, maintainability, and supportability, which has resulted in diminished operational availability and an increase in life-cycle support costs. Despite attempts to alter this continuous decline with various modifications, the AN/SPS-48E radar continues to operate below acceptable levels. The ROAR program was initiated to reverse this trend and respond to the need for a system redesign that introduces

- A sustainable OA processor
- More reliable and current technologies
- Improved diagnostics
- A performance-based product support strategy

Open Architecture Design Approach

The primary objective of the U.S. Navy OA initiative is to design and build affordable naval warfare systems that support current performance requirements, reduce future potential performance upgrade costs, and achieve portability, modularity, and interoperability throughout their life cycle. To comply with this initiative, the

AN/SPS-48G(V)1 has been designed to meet the U.S. Navy-defined Open Architecture Computing Environment (OACE) Category 3. This designation requires a fully OACE-compliant application implementation and infrastructure, including use of a Portable Operating System Interface for Unix (POSIX)-compliant operating system and Object Management Group (OMG) Data Distribution Service (DDS) publish/subscribe middleware. With the implementation of this standard, a baseline for interoperability among systems with minimal integration effort has been established as illustrated in Figure 1.

Redesign With Current Technology

To address the current and emergent obsolescence issues within the AN/SPS-48E Radar system, and in recognition of system reliability, maintainability, and cost drivers, the AN/SPS-48G program effort follows a practical design approach with several major modifications. The first major item is the introduction of a new solid-state, single-stage amplifier to replace the unreliable and costly AN/SPS-48E microwave tube-based First- and Second-Stage Amplifier. This new unit consists of 180 solid-state, radio-frequency amplifiers (RFA) installed in an architecture that provides redundancy and allows for graceful degradation. This solid-state design was prototyped and tested in the late 1990s and provides a highly reliable and stable output for further amplification in subsequent stages of the transmitter. This new solid-state, single-stage amplifier will substantially increase system availability while significantly reducing transmitter maintenance time.

The second major modification is the new Receiver/Processor unit, which completely replaces three units from the SPS-48E System (the Receiver, Processor, and Auxiliary Detection Processor units). This replacement results in an 87% reduction in unique lowest replaceable units (LRUs), reduces the number of RF cables from over 200 to just 33, and eliminates thousands of backplane

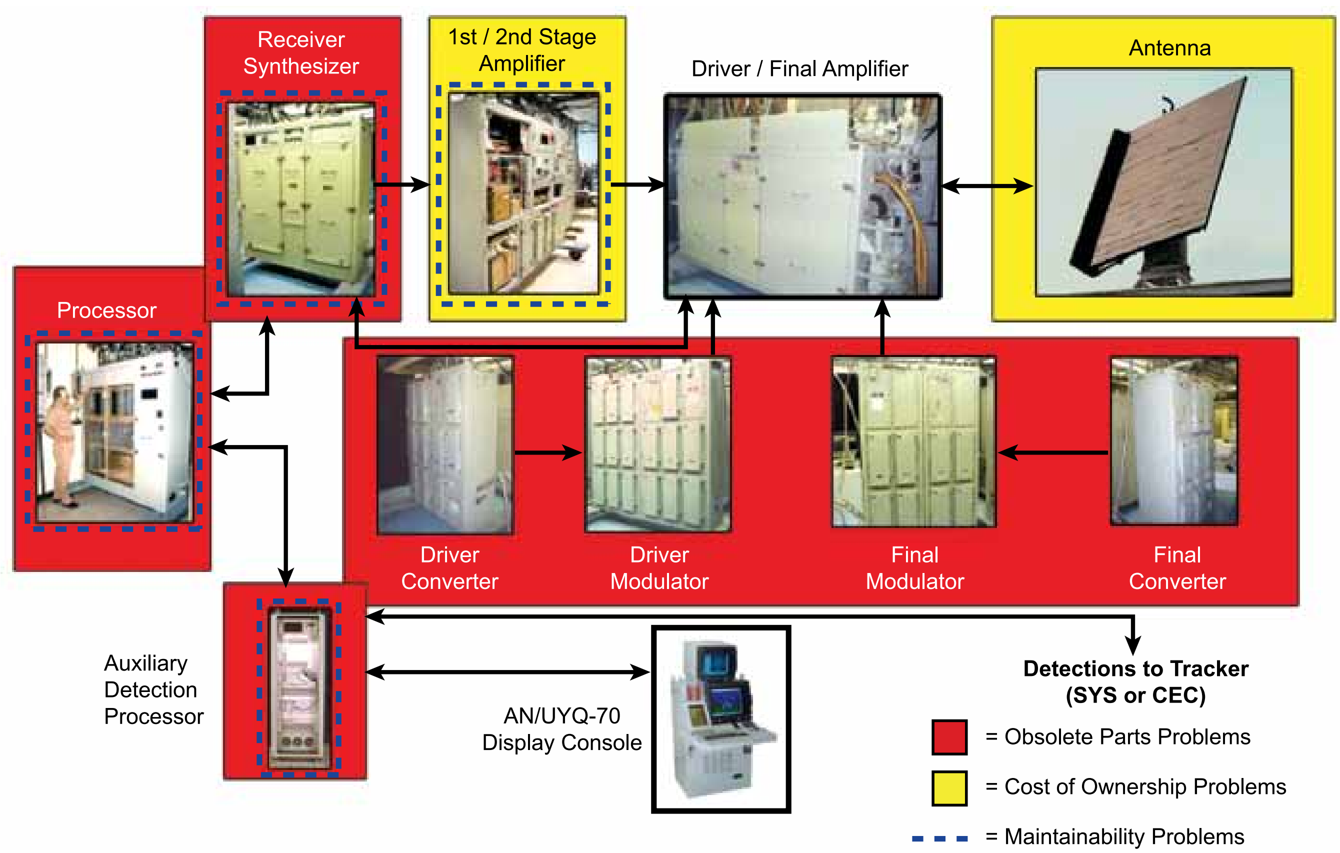


Figure 1. AN/SPS-48E Radar Obsolescence, Cost, and Maintainability Problem Areas

wires, resulting in a marked improvement in system reliability and availability.

Through the use of redundant commercial off-the-shelf (COTS) single-board computers hosted in an VMEBus VITA 41.3 architecture, the OA processor design will ensure the sustainment of the COTS-processor computing environment through a cost-effective tech-refresh program (see Figure 2). Maintainability and supportability improvements result from an improved maintenance system centered on a more comprehensive and intuitive Built-In Test (BIT) function that is fully integrated with embedded technical data, job aids, and training.

Performance-Based Product Support Strategy

Although the AN/SPS-48G(V)1 system is designed to fulfill the AN/SPS-48E top-level performance requirements, the philosophy of supportability is substantially different. For this system to be in service beyond 2030, the program applies new, innovative concepts into the design by developing a product support strategy that synchronizes traditional support elements into a performance-based environment. Responding to policy guidance OPNAVINST 1500.76, the AN/SPS-48G(V)1 radar design reduces the number of organizational-level maintenance tasks and the time required to

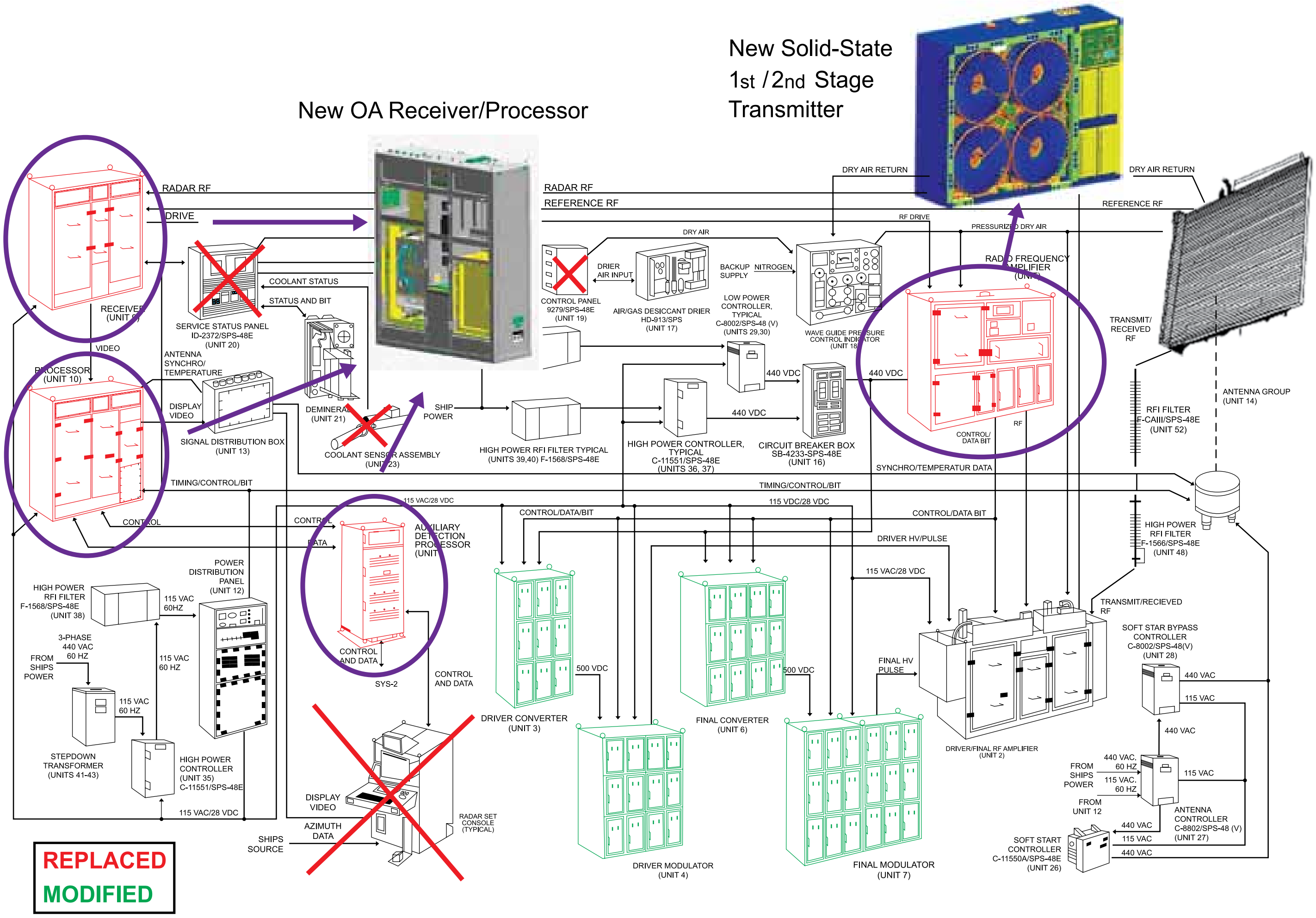


Figure 2. AN/SPS-48G(V)1 Radar System Hardware Modifications

perform these tasks by 62%. The AN/SPS-48G(V)1 employs a new Maintenance System that improves maintenance accuracy, reduces the time and cost to repair, and reduces the knowledge and skill level requirements to effectively perform maintenance.

The Maintenance System consists of an expanded BIT function that includes:

- An embedded Diagnostician package
- An embedded Technical Integrated Digital Environment (TIDE)
- A Radar Display and Control Function (RDCF)

The improved fault-isolation accuracy of BIT, coupled with reduced system complexity, makes it possible to employ a performance-based maintenance strategy. The key paradigm shift to note is that the maintenance methodology focuses the shipboard technician on what, when, and how to perform system maintenance, not on understanding volumes of technical information in order to maintain the system. The integrated maintenance system triad of BIT, TIDE, and RDCF creates, prioritizes, and schedules maintenance sessions to perform all corrective and preventive maintenance actions. All of the procedural and technical information necessary for the technician to perform the maintenance action is intuitively presented at the RDCF when the technician activates a session. Using the established Distance Support network, expert technicians ashore will assist with fault isolation when BIT cannot isolate the fault to one LRU or when the task is beyond the immediate knowledge and skill level of the onboard technician. The maintenance system components are depicted in Figure 3.

This new maintenance strategy also results in a significant reduction in the training requirements for the system. A Job Task Analysis was performed and identified the system-specific knowledge and skill gaps that are not satisfied by the existing apprentice training pipeline and embedded Maintenance System. To compensate for these knowledge and skill gaps, training for the SPS-48G technician includes 3 weeks of hands-on familiarization training to be taught at the Center for Surface Combat Systems facility at Dam Neck, Virginia.

Conclusion

Responding to the need for improvements in reliability, maintainability, and supportability, the ROAR program is a unique radar system that offers an OA-based system upgrade that decouples hardware and software to allow for affordable future technology growth. The simplified design has successfully implemented a methodology that reduces the number of maintenance-significant items and organizational-level maintenance tasks, as well as the knowledge, skills, and time required for shipboard maintenance. These changes will drive the system to achieve and sustain an increased operational availability, while at the same time lowering its life-cycle costs.

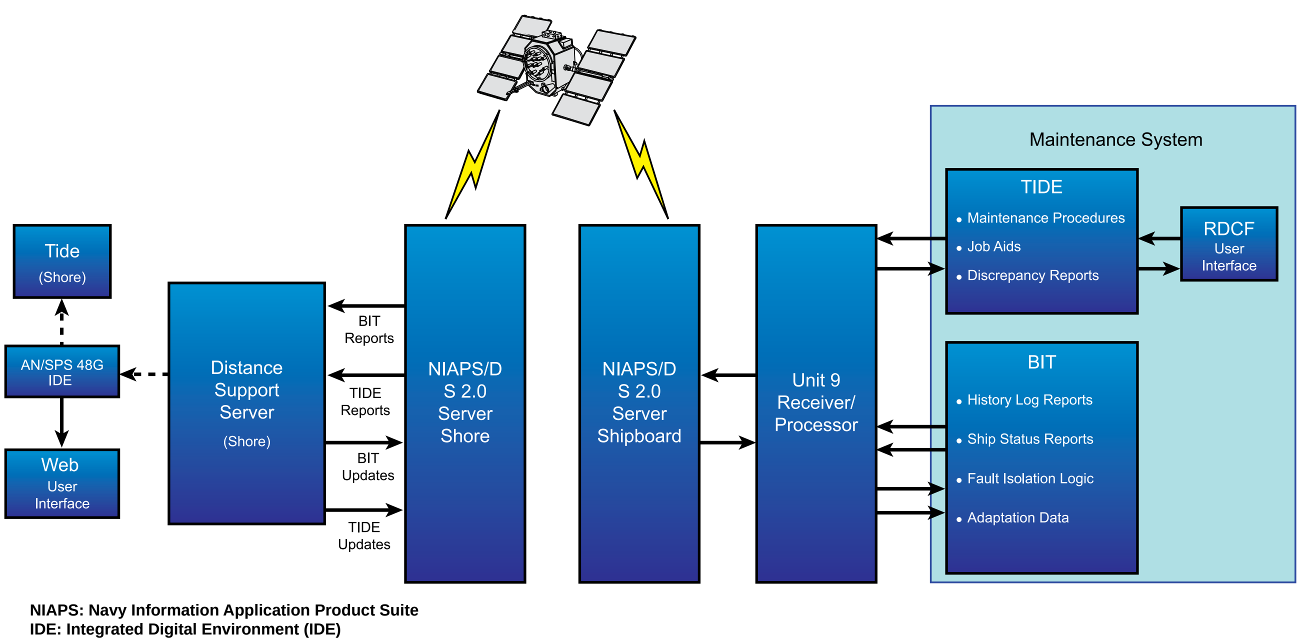


Figure 3. AN/SPS-48G(V)1 Maintenance System Components

Technical Authority and the Future of Radar

By Roger Kniceley

Radar systems have been critical to the Surface Navy since the initial introduction of the CXAM radar installed on the battleship *California*; the aircraft carrier *Yorktown*; and the heavy cruisers *Pensacola*, *Northampton*, *Chester*, and *Chicago* in 1940. Since that initial introduction, radars have been expected to improve their functionality and performance. Performance has increased from basic detection of ships and aircraft for self-protection and gun fire control to the present requirements to detect and track maneuvering, sea-skimming missiles, as well as the discrimination of lethal objects from ballistic missiles. Radars have also evolved from stand-alone systems with raw video displays to being fully integrated in the fire-control loop and the force-level network of sensors able to provide situational awareness over hundreds of miles. With this increased complexity comes the need for more rigorous systems engineering and coordination to ensure that the "system of systems" is properly integrated, interoperable, and meets the functional and performance requirements.

Defense Acquisition System Department of Defense (DoD)

DoD Instruction 5000.2 provides the policies and principles that guide all acquisition programs and defines a Systems Engineering Technical Review (SETR) structure to balance performance and cost while managing risk. Along with this basic systems engineering structure, the Systems Commands (SYSCOM) have been entrusted with execution of the "Technical Authority," which is the authority, responsibility, and accountability to establish, monitor, and approve technical standards, tools, and processes. The goal is to employ consistent, disciplined collaborative engineering processes that provide safe, reliable, effective, integrated, timely, and affordable systems.

Technical Authority Warrant

Virtual SYSCOM Engineering and Technical Authority Policy, VS-JI-22A, defines the engineering and technical authority policy and actions needed to support program managers (PMs) and the fleet in providing best-value engineering and technical products. The instruction defines the Technical Authority roles and responsibilities of the SYSCOM Commanders, the Deputy Warranting Officers, and the Technical Warrant Holders (TWHs). VS-JI-22A lists the following responsibilities of TWHs, organized by the seven competencies critical to being entrusted and empowered as a TWH.

1. Setting Technical Standards—Establish technical policy, standards, tools, requirements, and processes, including certification requirements.
2. Technical Area Expertise—Provide technical advice to the fleet, depot chief engineers, and other DoD customers. Maintain technical expertise and interface with the Science and Technology (S&T) community.
3. Ensuring Safe and Reliable Operations—Ensure that safety and reliability are properly addressed in technical documentation. Ensure that products are in conformance with technical policy, standards and requirements. Where they are not, identify options and ensure that risks are technically acceptable.
4. Systems Engineering Expertise—Ensure engineering and technical products meet Navy needs and requirements, including interoperability. Identify and evaluate technical alternatives, determine which are technically acceptable, and perform risk and value assessments.
5. Judgment in Making Technical Decisions—Provide leadership and accountability for all engineering and technical decision-making. Promote and facilitate communications to ensure that appropriate personnel and organizations are aware of, and are involved in, technical issues and technical decisions.
6. Stewardship of Engineering Capabilities—Ensure that an appropriate engineering and technical authority support network is established for the warranted technical area and provide leadership for the support network.
7. Accountability and Technical Integrity— Exercise integrity and discipline to ensure the soundness of technical decisions. Keep organizational Chain of Command informed of issues and decisions.

NAVSEA has a long history with Hull, Machinery, and Electrical (HM&E)-related TWHs. However, VS-JI-22A defines six types of TWHs, including: Platform Design Managers, Chief Systems Engineers, Cost Engineering Managers, Technical Process Owners, Depot Chief Engineers, and Technical Area Experts (TAE). Within the general category of TAE, there are several different competencies, including marine engineering, human systems, test and evaluation, and warfare systems. SEA05 has designated a number TWHs to support the various warfare system elements, including: guns, missiles, electronic warfare, electro-optics, and radar.

The scope of the Radar TWH includes the RDT&E, acquisition, and in-service support for all Surface Navy radars. To fulfill these roles and responsibilities, the TWH must work with the various radar system PMs in all phases of radar development. This is accomplished by maintaining open lines of communications, participating in the various SETRs, and generally maintaining an awareness of the various radar-system design and support issues. It is important to understand that TWHs in no way change the responsibilities of the Program Executive Offices (PEOs), Major PMs, or individual PMs. The TWH is intended to be a partner and independent source of expertise and review to help provide the best and most cost-effective products to the warfighter.

Radar TWH Activities

It is a very active time for the Surface Navy radar community, with systems in all stages of acquisition. The Radar TWH is not only involved in the development of radar systems, but also in the integration of those systems into combat systems and ships. Primary TWH involvement occurs at the SETRs; however, when properly integrated, there are numerous other opportunities for the radar TWH and PMs to collaborate. The following list will provide some insight into the scope and breadth of the Radar TWH role and support that has been provided:

General Radar Analysis and Concept Definition

- Review of the radar requirements and concepts for CG(X) and Future Surface Combatant
- Review of the Integrated Air and Missile Defense Layered Defense Study
- Assessment and monitoring of solid-state, high-power amplifiers and vacuum tube radio frequency (RF) source development
- Support for continued management of the Surface Navy Radar Roadmap

New Radar System Development

- Review and comment on the Air and Missile Defense Radar (AMDR) Capability Description Document
- Participate in contractual source selection
- Serve as panel member on numerous reviews for Dual-Band Radar (DBR) and SPY-1 Multimission Signal Processor
- Review and evaluate risk-mitigation activities associated with the DBR High-Power Module and radome development

Combat System and Ship Integration

- Review of DDG 1000 Combat System simulation strategy
- Assess and recommend for DBR integration with Battle Force Tactical Trainer for CVN 78
- Review of the improved sensor integration architecture and algorithms for the Amphibious Improvement Program
- Review and recommend for TRS-3D radar performance analysis for the littoral combat ship (LCS)

Deployed System Support

- Investigation and analysis of root cause for Aegis SPY-1 radar adaptation data issues
- Investigation and study of operational radar and commercial system interference

Future Radar System Focus Areas

We are approaching the point where technology is available to design a radar system that can satisfy almost any foreseeable performance requirement: detection of missiles as they come over the horizon; detection, resolution, and identification of threats at hundreds of miles; and accurately tracking and correlating maneuvering threats from multiple sensors to create a complete situational awareness over the entire theater. However, that does not mean that S&T and systems engineering are not required. There are still many critical problems that must be addressed that require broad community attention and coordination.

One of the primary concerns for future systems is procurement cost. Future radar systems are projected to cost hundreds of millions of dollars to develop and an equivalent amount to procure one deployable system. While these costs may be justified for major combatants, the Navy needs lower cost radar systems that can be affordably developed, integrated, and installed on smaller ships. Focus must be maintained on this objective as we develop the future AMDR so that both hardware and software components can be used to quickly and economically develop and build less-capable variants.

Another important aspect of reducing future costs is driven by system efficiency. Historically radar systems have had to deal with significant transmit, receive, and processing losses. To compensate for these losses, radar designers increased transmit power or antenna size. Modern phased-array radar systems have gotten rid of most of these losses but now suffer from low-efficiency, high-power modules. The low module efficiency does not directly impact system performance; however, it does drive the size of the radar power supplies and cooling systems and, therefore, impacts radar system weight, which—for very high-performance radars—can become a significant driver for the overall ship's power generation system.

Legacy and RF Systems

The above focus areas were concerned with new radar systems, but legacy systems also require S&T investment. Many of the radar systems currently in the fleet will still be operational for more than 20 years. Many of the components in these systems are already obsolete and will not be supportable in the future. There must be a coordinated effort to look across these radar systems, and develop replacement systems and support processes that are affordable and supportable for the projected operational life.

Another focus area is applicable to all RF systems, not just radars. The Navy has been a leader in dealing with electromagnetic interference (EMI) and electromagnetic compatibility (EMC) given the close proximity of large numbers of RF systems. In the past, the primary tool was simple spectrum coordination and management. However, with most new major radar systems being developed at either 3 or 10 GHz, it will be difficult to solve EMI/EMC issues using this technique. With the exponential growth in demand and reliance on wireless telecommunications, the RF spectrum is becoming increasingly crowded, especially in developing areas of the world. This is compounded for the Navy since a significant portion of the world's population live in coastal areas. Thus, there is an increasing demand and opportunity for S&T investment in spectral noise reduction, innovative spectrum sharing, and management techniques.

Summary

The future for radar systems presents many challenges. These challenges go beyond the traditional pursuit of increased functionality and performance, and require rigorous systems engineering and technology investments focused on solutions that benefit more than a singular radar system. The Technical Authority and the Radar TWHs play a pivotal role by providing an independent review of individual system developments; establishing and coordinating standards, tools, and processes; and helping identify critical focus areas that will help develop, field, and support the radar systems that the Surface Navy needs.

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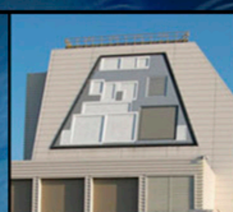

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