INNOVATION

OFFICE OF NAVAL RESEARCH VOL. 9 | FALL 2012

WARFIGHTING IN A HIGHLY-CONTESTED ELECTROMAGNETIC ENVIRONMENT

CONTENTS

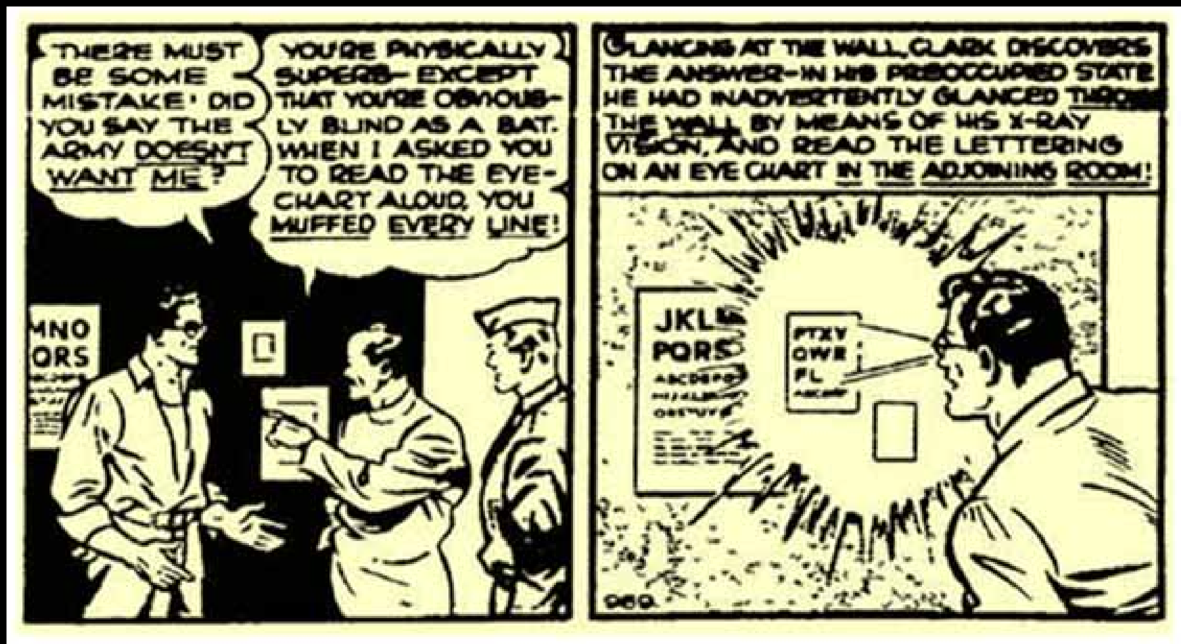
ELECTRONIC WARFARE IN A CONGESTED SPECTRUM

SUPERVISION VERSUS SUPER-VISION

Peter N. Craig, Ph.D. – ONR Program Manager, Electronic Warfare

We are all familiar with Superman's power of x-ray vision, his ability to see through objects and spot items that are hidden to normal sight. Indeed, this is such an enduring characteristic of the superhero that it persists even today after being first introduced in the eleventh comic book adventure of Superman in 1939. Less familiar to the general public is Superman's power of "super-vision"; a catch all that includes telescopic-vision, microscopic-vision, and – finally arriving at the point of this article – the ability to perceive all other parts of the electromagnetic spectrum (EMS), including ultraviolet, infrared, and even radio frequency (RF) emissions. In this construct we see that his more famous x-ray vision is merely a subset of a more comprehensive power of perception. (A necessary legal footnote: Superman, besides being a "strange visitor from another planet, with powers and abilities far beyond those of mortal men!", is also trademarked and copyrighted by DC Comics.)

Even as a kid reading comics in the 60's, I recognized the use of Superman's super-vision as *a deus ex machina* likely introduced by a desperate writer who had plotted himself into a corner. Later, as a budding physicist in the 70's, it was often amusing to speculate on translating Superman's powers to the real world; realizing, for instance, that for Superman to generate a strong enough focused beam of x-rays to power his x-ray vision, the OSHA of his universe would likely require that he replace the red "S" on his chest with the universal symbol for radiological hazards. But even in my current capacity as the Electronic Warfare (EW) program manager at ONR the value of Superman's super-vision is worth consideration. EW is usually thought of in terms of its more flashy aspects; for example, using lasers directed against heat-seeking missiles to cause them to miss their target. Just as – to carry the analogy even further – Superman's heat-vision has always been flashier than his x-ray vision. But before we can use



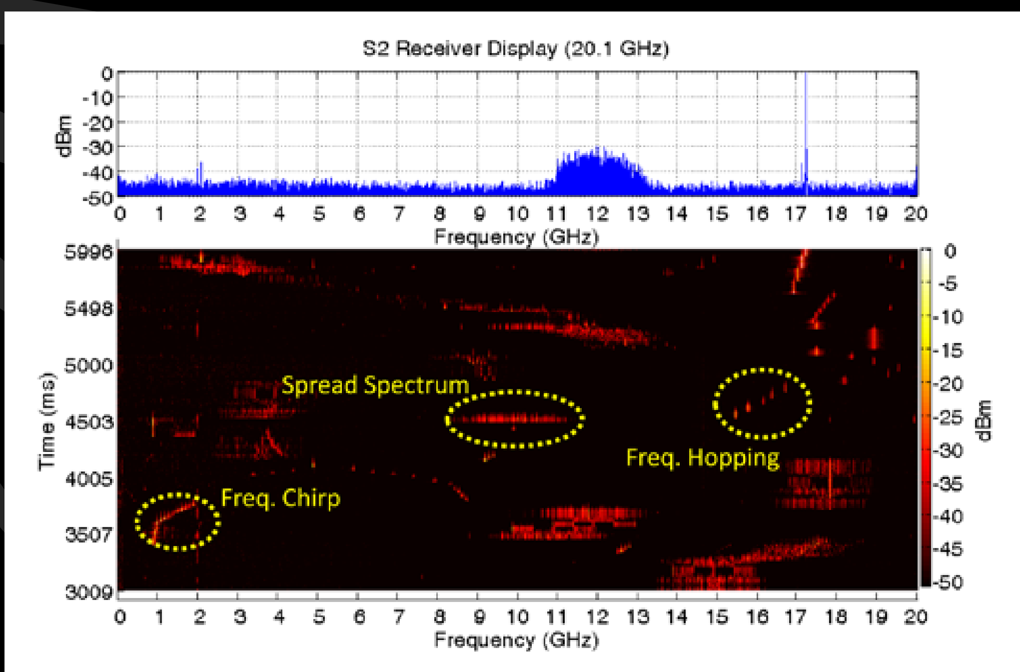
Ever wonder why Superman never joined the military? These panels from the February 18, 1942 Superman newspaper comic strip reveal the truth: he couldn't pass the physical! In his excitement to join up he triggered his x-ray vision during the eye exam and accidently read from the eye chart in the next room. So Clark Kent was forced to sit out World War II as a civilian. You're welcome Axis powers! (SUPERMAN is ™ and © DC Comics. Used with Permission.).

a laser to counter a missile we need to know that the missile is in the air and attacking us. That aspect of EW – sometimes called "threat warning" but more often generalized to encompass all forms of passive sensing of the EMS – is called EW Support and abbreviated as ES. An ES system that can sense across the entire EMS all the time would truly be a "super" thing to possess.

The EMS is vast, whether it is measured in terms of frequency, as is common for RF radiation, or in terms of wavelength, as is common for the electro-optical (EO) portions of the spectrum. Which is what makes Superman's super-vision so impressive and, ultimately, so unlikely. Most systems that operate in the EMS do so across very limited spans. Radar, communications, surveillance, and reconnaissance system bandwidths are often considered wideband if they span megahertz (MHz) frequencies and seldom span more than a few gigahertz (GHz). But an ES system, without the luxury of an *a priori* knowledge of what a source of unknown EM radiation is being used for, must span many orders of frequency. In fact, one can argue that any limitation on the band coverage of an ES system is an open invitation for our adversaries to hide their operations from our knowledge and scrutiny. Current efforts to manage the EMS, through legal partitioning of the spectrum or international treaty, are necessary and even laudable goals to supervise the increasing congestion in the more heavily used portions of the spectrum. But laws and treaties are only applicable to those who choose to obey them. President Reagan's "trust, but verify" becomes a greater sentiment when it comes to monitoring the EMS than it was originally intended in the context of nuclear brinksmanship. To put it glibly, in light of the limitations of EMS supervision, there is still a need and desire for "super-vision." But is it even physically possible?

Dr. Kris Merkel and other researchers at the S2 Corporation, a small business in Bozeman, Montana, and their collaborators at Montana State University are among several groups that are pushing the limits of ES systems in monitoring the EMS. Using methods of translating wide swaths of the RF spectrum into the optical domain – by modulating the RF spectrum onto a coherent laser beam – where they are much more manageable, it is possible to imagine ES systems that span 10s and perhaps even 100s of GHz without any gaps. Work by S2 (an abbreviation for "spatial-spectral holography") in this area has been supported by all the services at various times, though most recently by the ONR Discovery and Invention (D&I) program and an ONR-sponsored Small Business Innovative Research (SBIR) contract. This ONR investment has resulted in a system that can simultaneously monitor all EMS emissions over a span of 40 GHz while resolving signals that are separated by only a few 10s of kilohertz – and continuing research will increase this span to greater than 100 GHz. The system creates, in essence, a "super-vision" of the EMS where such signal techniques as frequency hopping, chirping, or spectrum spreading become visible as patterns in a real-time frequency map. This is by no means an easy process and the technological challenges have been formidable. Recent breakthroughs in ultra-stable lasers, electro-optical materials, and mechanical systems operating at cryogenic temperatures only a few degrees above absolute zero have enabled this technology. Being able to realize these capabilities in the context of tactical military ships or aircraft will require additional development.

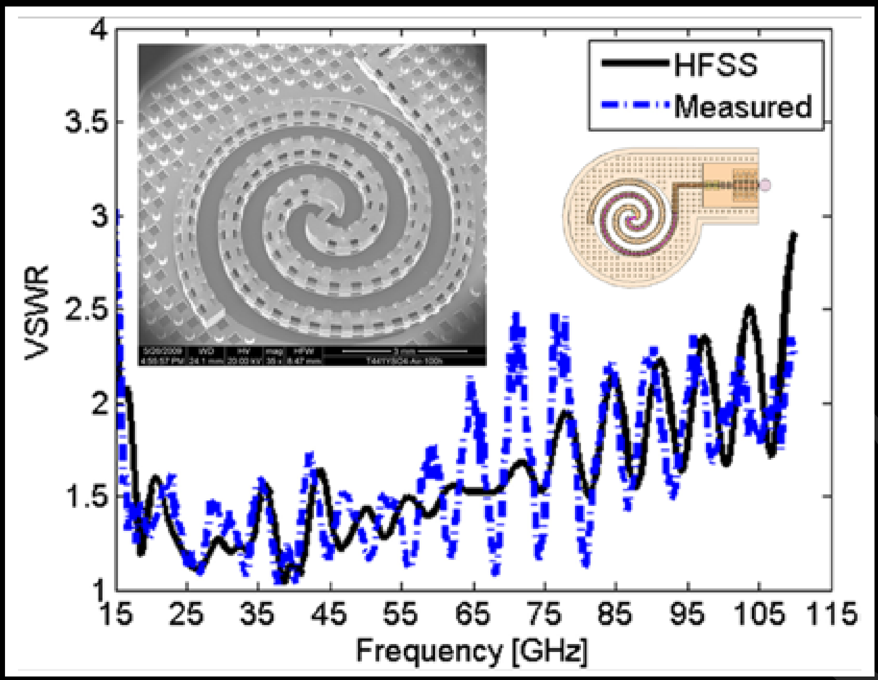
When attempting to develop EW systems that cover decades of frequency every part of the system is impacted, but none more so than the entry point to the system: the antenna. Traditional antenna designs for radars and communications systems become a chokepoint when designing systems spanning the EMS. This makes the work of Professor Dejan Filipovic and his students at the University of Colorado all the more impressive. Under an ONR D&I effort entitled "Antennas from VHF to THz" this group developed antenna designs covering



An example of a time history of RF emitters in the frequency range from 0 to 20 GHz using technology developed by researchers at the S2 Corporation. Time is on the vertical axis and the plot is updated approximately once every millisecond (a single time slice is graphed above the plot). Frequency resolution on the horizontal axis is better than 1 MHz and examples of frequency chirping, frequency hopping, and spread spectrum signals are easily observed.

over 100 GHz, making breakthroughs not just in designing and arranging antenna elements but also in the impedance-matched feeds, phase-shifters and mode-forming networks that could ultimately limit system performance. Power handling was also a design consideration, because these antennas were considered not just for ES applications, but also for enabling wideband Electronic Attack (EA) systems – also known as "jammers." Through analysis and experimentation with conventional antenna types such as cavity-backed multi-arm spirals and end-fire planar log-periodic dipole arrays they achieved realizable designs covering 100 MHz to 3 GHz (VHF to S band), 10 to 50 GHz (X band to Ka band) and even 2 to 110 GHz (S band to W band). In the process they also discovered many design rules and integration methods that will influence the designs of EW antennas for years to come. No less importantly, this work was the subject of four doctoral dissertations and research performed by multiple undergraduate, graduate, and post-doctoral students who will become the scientists and engineers developing our future EW systems.

Superman is a hero of comic books, comic strips, cartoons, TV, and movies who possesses near-god-like abilities that cannot ever be fully realized in our grounded, day-to-day reality. But sometimes the imagination of creators of fiction that have long since passed away can point toward a vision that science and technology could and should aspire to, and might even achieve in our lifetimes. In a world with a congested and choked EMS, such a "super-vision" just might introduce a little breathing room. ■



A plot of simulated and measured VSWR (a measure of the impedance match between an antenna and a receiver) for a spiral antenna developed by a team at the University of Colorado using micro fabrication techniques. Insets on the right and left show the antenna layout and a microphotograph of the antenna as fabricated. The plot shows excellent performance (VSWR < 3) over frequencies spanning 15 to 110 GHz.

www.onr.navy.mil/innovate

Vol. 9 | Fall 2012

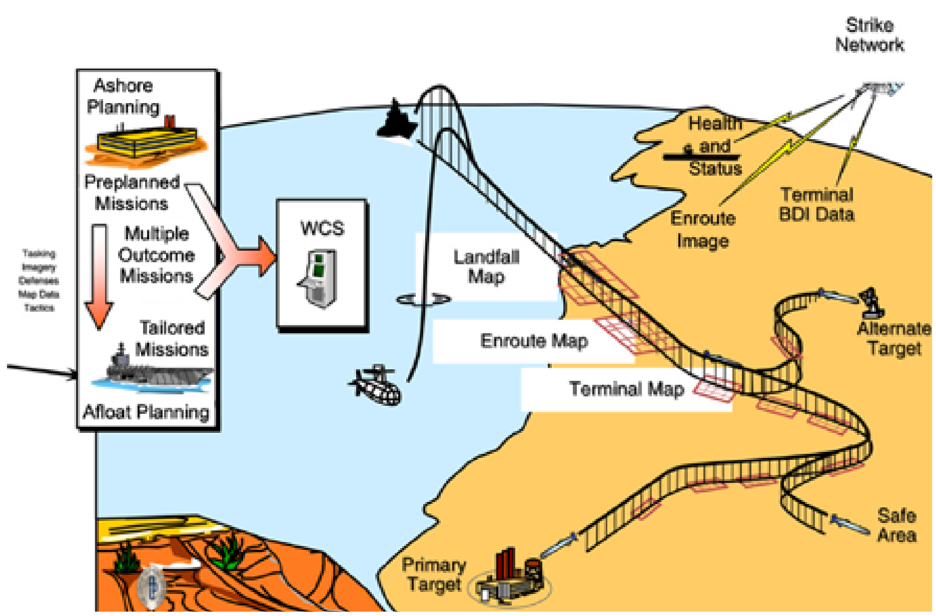
BEYOND GPS

FUTURE PRECISION NAVIGATION AND TIMEKEEPING FOR NAVAL FORCES

John Kim, Ph.D. – ONR Program Manager, Navigation and Timekeeping

The ONR Navigation and Timekeeping Technology Program is investing in new and innovative navigation technologies that will provide more accurate, reliable, maintainable and affordable systems for Naval Air, Surface, Subsurface, and Ground Platforms and Forces.

Precision navigation and timekeeping are essential functions of many modern Naval and Maritime Systems. It is critical that navigation and timekeeping services be made available to platforms and weapons at the highest level of accuracy and with the highest possible confidence, while being of reasonable cost. Lack of precise navigation and timekeeping technologies may jeopardize the success of military operations. For example, the Global Positioning System (GPS) provides highly accurate position/time information at low cost and as a result, GPS has become the technology of choice for many users. Unfortunately, the GPS signal is a low-power signal that is susceptible to interference. Therefore, there is a need for affordable approaches to make GPS more reliable/robust, methods of quantifying threats to GPS performance, and affordable and reliable precision navigation/timing alternatives to GPS.



Mission planning using diverse navigational approaches.

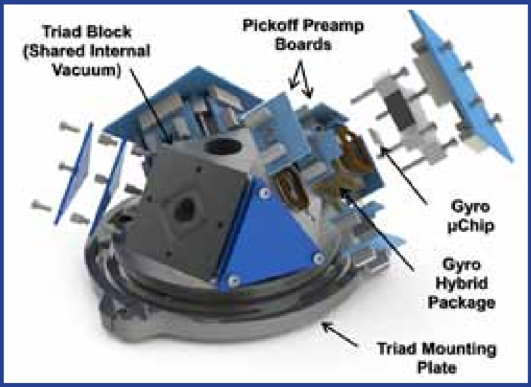
Up until the 1980's, naval platforms navigated by using spinning-mass gyros and inertial devices: aircraft used strap-down gyros and altimeters; ships and submarines used INS and Loran Radio Navigation; and vehicles and weapons used spinning-mass gyros. In the past, naval platforms obtained time references from on-board organic frequency standards and/or by a radio broadcasted time source. Since the 1990's, with the advent of the GPS system, most naval platforms rely upon GPS for navigation and for providing precision time. The success of GPS for naval precision, navigation and timekeeping (PNT), however, puts too much responsibility in one system for these operationally critical functions. The PNT community, both the user and the acquisition communities, have spent the last fifteen years researching and developing methods that mitigate GPS interference. Some approaches have utilized antenna nulling and antenna electronics to suppress interference.

The ONR PNT Program has been one that employs diversified approaches in a balanced program plan with an emphasis on making non-GPS PNT readily exploitable and operationally available.

In the future, a commercial transport aircraft could navigate from Dulles International Airport to Charles de Gaul Airport (CDG) via an inertial navigation system and an associated atomic clock, completely without a GPS system. To accomplish this one may need a half dozen way-point corrections, using land marks, or updating clock functions using RF sources. This approach will certainly allow a pilot to find Paris, and with high probability, the appropriate runway at CDG.

ONR has been investing in various non-GPS navigation and small, accurate atomic clocks. Specifically:

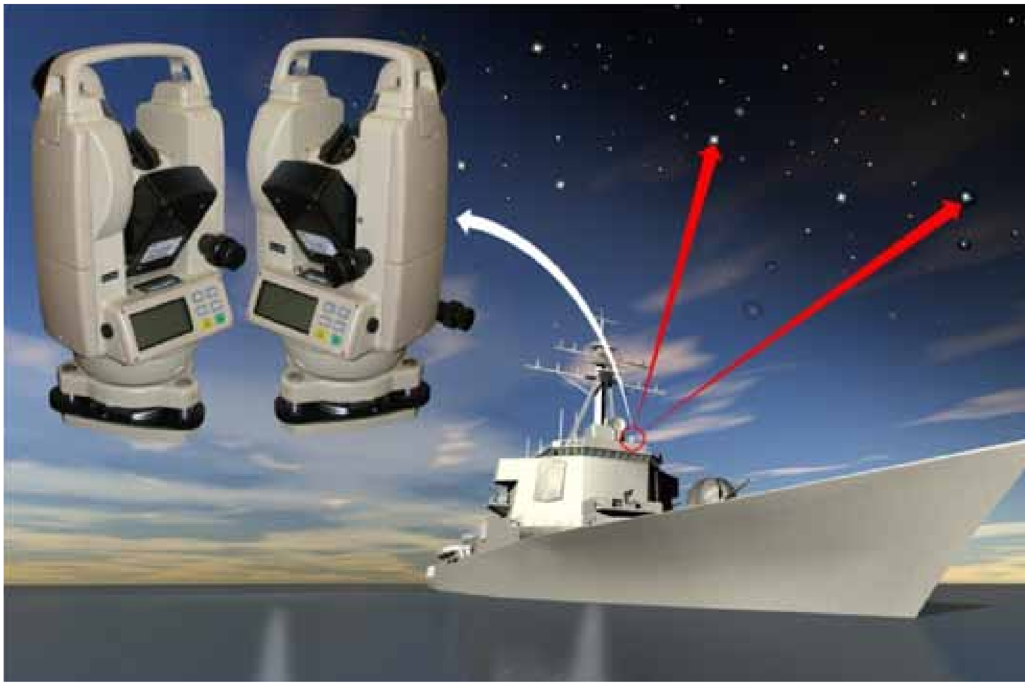
- Celestial Navigation, starting initially with 10 meter positional accuracy and extending that to 3 meter accuracy, equivalent to present-service GPS;
- Advanced Technology Inertial Navigation employing Fiber Optics, MEMS, and Quantum Mechanical approaches;
- Advanced Technology Magnetic Navigation

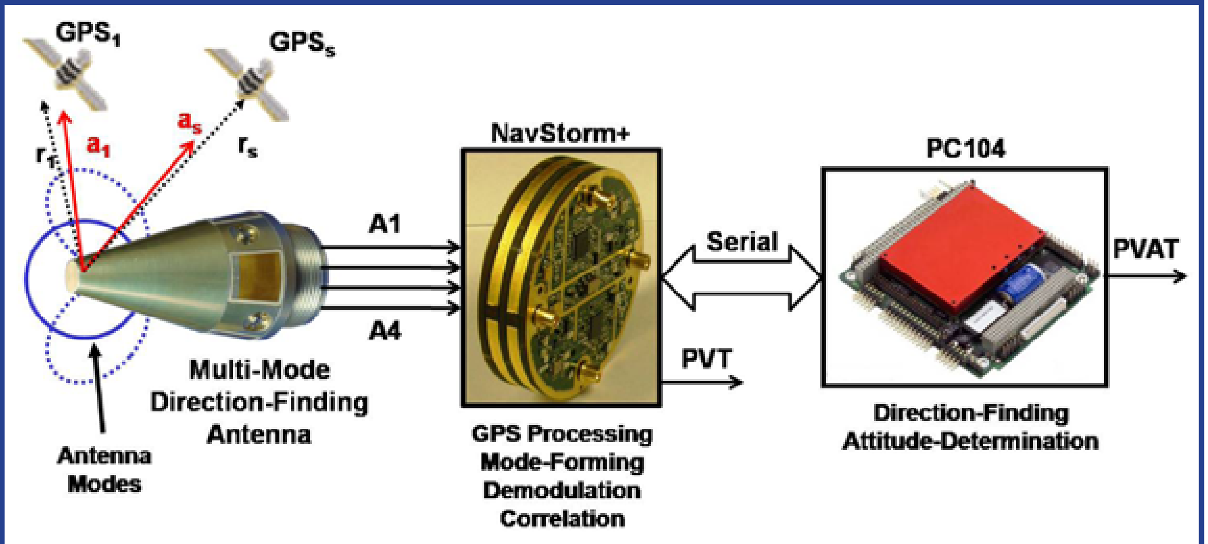


Navigation-grade MEMS, inertial sensor assembly.

Tactical-grade Atomic Clock, volume: <3 cm³, power: <100 mW.

Shipboard, Precision celestial navigation system.





GPS antenna for small, less than 5 inch diameter airborne systems.

(using Superconducting Devices);

- Bathymetric Navigation of the seafloor using acoustical imaging;
- Gravimetric Navigation using seafloor mass-density differences;
- Image-based terrain-feature-following Navigation.

Naval forces need to know where they are, they need to know how to travel to new mission areas, and they need to be aware of precision time in order to be on-location precisely when needed.

GPS, by itself, can provide this necessary information. However, satellite-based GPS information can be denied through a range of interference methods. The ONR Navigation and Timekeeping Program has improved GPS's resistance to intentional interference by more than three orders of magnitude in the last decade. Although this effort to increase robustness continues, other efforts that are stand-alone/stand-apart with respect to GPS have been pursued in order to ensure that one's position is always precisely known. Every effective navigational metric has been explored and the best are undergoing multiple-pass performance refinement efforts.

Knowing one's position to three meters and knowing universal time to less than a microsecond are possible even for the smallest of naval platforms and the most isolated individual warfighter. Robust GPS systems affiliated with back-up systems of equivalent performance, provide the operational confidence that our forces require. The ONR effort continues to introduce and refine technologies for this important function. ■

ENABLING DISTRIBUTED ELECTRONIC WARFARE

Mr. David Tremper – Program Officer, Code 312 Electronic Warfare

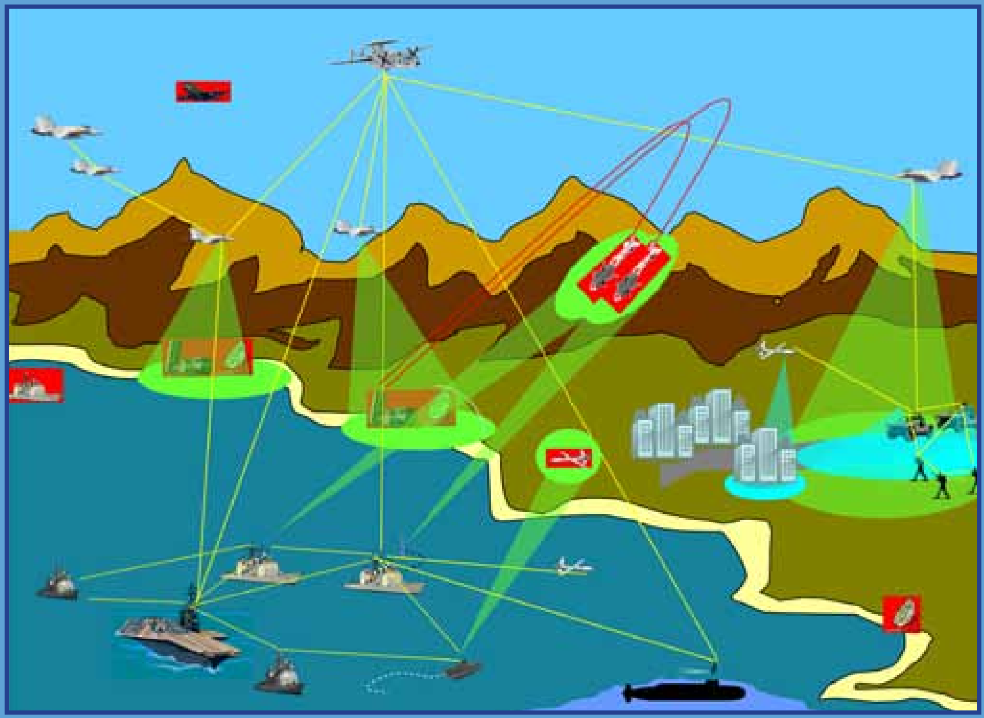
The ONR Code 312 Electronic Warfare (EW) Program Office has been pursuing the development of new EW systems, payloads and capabilities for application to manned and unmanned platforms across multiple operational domains, including ground, surface, sub-surface and air. This proliferation of EW technology will enable new capabilities to be readily available within the battlespace, but has also highlighted new challenges, including the development of platform-agnostic, capability-based payloads, efficient use of distributed EW resources, and spectrum management of concurrently operating RF functions. ONR Code 31 EW has been considering these challenges while working with acquisition program offices across all operational domains to address requirements and desired capabilities of specific platforms through EW S&T investment in Discovery and Invention (D&I), Future Naval Capability (FNC), and Innovative Naval Prototype (INP) initiatives.

Of particular interest, in the pursuit of distributed EW functionality, is the development of software programmable, capability-based, multi-function payloads which can be integrated into a variety of platforms. The software programmable and capability-based characteristics enable cost-efficient technique development, integration, and reuse with rapid upgrade and maintainability. As an example, the Code 31 EW Enabling Capabilities (EC) 'Next Generation Countermeasures (NGCM) for Ship Missile Defense' and 'Coherent EA for Submarines (CEAS)' are pursuing payloads for insertion into Programs of Record (POR) in support of surface ships and submarines, respectively. However, because both efforts are pursuing programmable, capability-based payloads, the core hardware and functionality is being developed to enable quick adaptation to other PORs or platforms, both manned and unmanned, effectively enabling rapid insertion of the capability into other operational domains when needed.

In addition to being capability-based, EW payloads which provide Radio Frequency (RF) multi-functionality, or 'multi-personality', allow common hardware and processing to be shared across various RF functions, such as EW and communications, within a single system. The underlying architecture in such payloads allows system-level resource allocation management techniques and algorithms to be developed and inserted which can coordinate the use of shared RF hardware and digital processing, as well as the use of the RF spectrum. This capability is particularly useful for Size, Weight, and

Software-programmable payloads enable the core digital hardware and processing resources to be reused across a variety of EW applications and operational domains, while modular analog RF front-ends allow the payload to be rapidly tailored for the particular spectrum of operation.

Software-programmable, capability-based EW development allows for the rapid insertion of new EW functionality across operational domains to both manned and unmanned platforms. However, networked coordination and battle management of the resulting distributed EW battlespace is required to enable efficient EW operations and deconflict RF resources which are sharing the same spectrum.



Power (SWaP) constrained platforms where EW functionality is desired. ONR is currently exploring such multi-function payloads within the Future Joint Counter Radio Controlled Improvised Explosive Devise EW (JCREW) EC, as well as within payload development efforts for unmanned platforms.

As EW payloads continue to be applied across the battlespace, developing the networking and coordination between payloads becomes more critical in order to enable efficient, deconflicted and coordinated blue force spectrum utilization. While this coordination capability is of interest today, it's need becomes particularly clear when considering the future EW battlespace which will result from readily-available and inherently-networkable EW payloads and the continued proliferation of unmanned platforms performing EW operations. ONR Code 31 EW has multiple EC initiatives addressing the coordination of EW resources, including 'Future JCREW' for ground operations, 'EW Battle Management (EWBM) for Surface Defense' and 'Collaborative Electronic Attack (CEA)' for air operations. In addition, the ONR Code 31 EW INP 'NEMESIS' will be exploring coordinated and networked EW from combined manned and unmanned operations.

The ONR Code 31 EW Program Office is in a unique position to work across a variety of operational domains and understand the common EW capabilities and technologies which cut across systems. This perspective allows the EW Program Office to pursue technologies in support of particular platform requirements while at the same time, considering the utilization and application of the capability toward other platforms within other operational domains. The resulting capability-based development allows for efficient technology development which can be leveraged toward other applications and, as a result, provides 'bang for the buck'. ■

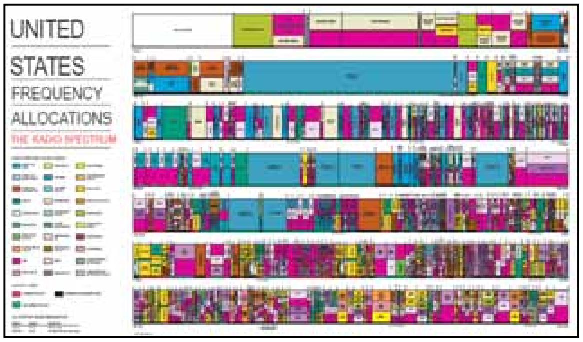
TRANSFORMING EM SPECTRUM ACCESS AND MANAGEMENT FOR THE DEPARTMENT OF DEFENSE IN THE 21ST CENTURY

Santanu Das, Ph.D. – ONR Program Manager, Communications and Networking

The current naval force relies upon information superiority and a dispersed, networked force to deliver unprecedented offensive power, defensive assurance, and operational independence to Joint Force Commanders. The 21st century set the stage for tremendous increases in naval precision, reach, and connectivity through the integration of sea, land, air, space, and cyberspace to a greater extent than ever before. However, adversaries may try to degrade or negate the effectiveness of U.S. naval forces by disrupting our information superiority and thus impair the commander's ability to exercise command and control (C2) over assigned forces.

ANTI-ACCESS/AREA DENIAL

For example, China is developing measures to deter or counter third-party intervention, including by the United States. China's approach to this challenge, which it refers to as "counter-intervention", is manifested in a sustained effort to develop the capability to attack, at long ranges, military forces that might deploy or operate within the western Pacific. The U.S. Department of Defense characterizes these as "anti-access" and "area denial", or A2AD, capabilities. China is pursuing a variety of air, sea, undersea, space, counterspace, information warfare systems, and operational concepts to achieve this capability, moving toward an array of overlapping, multilayered offensive capabilities extending from China's coast into the western Pacific.[1]



COMMUNICATIONS CONDITIONS

Communications with tactical forces enable naval commanders to exercise C2 to support the actions and activities necessary to win the war. However, there is a finite amount of electromagnetic spectrum (EMS) and adversaries may try to degrade or deny it to naval forces. Therefore, Navy communications systems must be able to operate across a wide range of conditions:

- **Unconstrained.** Communications resources available are consistent with or potentially exceed what is typically available during day-to-day operations.
- **Constrained.** Communications resources are strained due to the flow of forces in theater and increased Joint requirements.
- **Contested.** Communications resources are degraded by adversary actions.
- **Denied.** Communications resources are potentially denied by adversary actions.

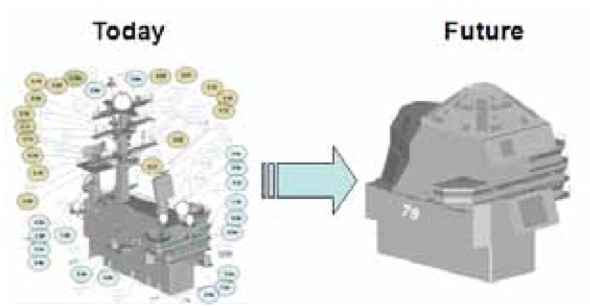
[1] Office of the Secretary of Defense, *Annual Report to Congress: Military and Security Developments Involving the People's Republic of China*, 2011. http://www.defense.gov/pubs/pdfs/2011_cmpr_final.pdf.

SCIENCE & TECHNOLOGY RESPONSE

The Office of Naval Research (ONR) is pursuing a number of different technologies to enable the warfighter to continue to communicate under these conditions:

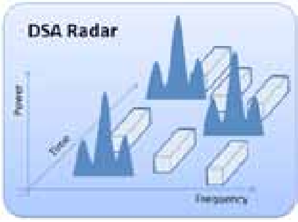
- **Spectrum Awareness.** The Radio Propagation Modeling in Complex Environments program is creating a software package for global radio propagation prediction in complex environments to give the warfighter the ability to predict the impact of different actions in the electromagnetic spectrum (EMS) on their systems. The Collaborative Networked Spectrum Awareness program developed real-time means for existing software-defined radios to scan and analyze the EMS to determine current conditions as well as adapt the radio parameters to preserve warfighter connectivity and throughput in under these conditions.
- **Compact, wideband communications systems.** The Electrically Small and Structurally Integrated HF Antennas program is producing metamaterial, conformal antennas that cover the HF, UHF, and VHF frequency bands. The Ku/UHF Blade Antenna System program is developing an integrated directional Ku/omni-UHF antenna that is a drop-in replacement for an existing UHF blade antenna on helicopters. Additional metamaterial antenna programs are trying to achieve 100:1 bandwidths and integrate the antenna into ballistic armor.

- **Multi-Functional Systems.** The Integrated Topside (InTop) program is delivering a scalable family of electronic warfare, radar, and communications capabilities to support different classes of ships and other Navy platforms. InTop is maturing several different technologies that are critical enablers for future spectrum sharing concepts: (1) electronics technology to improve linearity, efficiency and noise reduction while reducing size, weight, and power; (2) integration of these components into a compact, nested design for multi-function, multi-band,

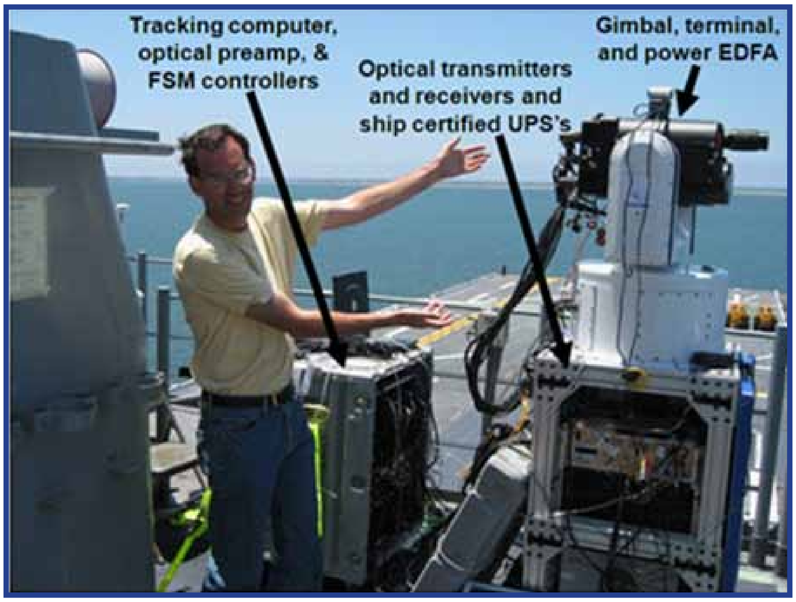


multi-beam arrays; and (4) innovative resource allocation manager to allocate RF resources on these arrays to different functions and, as required, pre-empt less important functions in support of specific mission objectives or to address inbound threats.

- **Cognitive communications.** The Cognitive Radar program is exploring approaches that enable radar systems to coexist with communications systems by improving performance while minimizing interference. The Non-Contiguous Dynamic Spectrum Access program is developing novel spectrum fragmentation techniques for communications across non-contiguous frequency bands. These programs are developing cognitive communications capabilities that make more efficient use of the EMS that is available.



- **Free-space optical communications.** The Tactical Line-of-Sight Optical Communications program is developing a full duplex, high bandwidth, optical terminal for the U.S. Marine Corps. Earlier free-space optical systems were successfully used for ship-to-ship communications in Trident Warrior 06 and 08. Optical communications operate outside military radio frequency bands in unregulated spectrum and the highly directional beams are very difficult to jam.



CONCLUSION

ONR is developing the technologies that enable the warfighter to understand how the EMS is being used while giving them the flexibility of choosing where and how they want to operate, as opposed to letting the limitations of communication systems dictate how operations are conducted. These capabilities will assure naval forces continue to maintain information superiority by assuring that naval commanders can exercise C2 over tactical forces despite the broad range of advanced A2AD threats in the 21st century. ■

A Marine Rifle Platoon recovers a water resupply delivered by a CH-53 in Now Zad, Helmand Province.

ENERGY SCAVENGING

EXPEDITIONARY LOGISTICS/WATER POWER

CAPT Frank Furman, USMC – ONR Program Manager, MILDEP Logistics Thrust

If it takes one unit of energy to power a radio, it takes more than one unit of energy to fuel the generator. That fuel takes additional energy to transport thousands of miles from the refinery to the generator. Energy scavenging aims to cut out the middleman. By cobbling together bits of energy from the surrounding environment, only the one unit of power the radio needs is produced.

Intense military interest has spurred recent research and investment in the field of energy scavenging. This has been driven by a number of desired capabilities: distributed operations, prolonged counterinsurgency campaigns, and the increasing energy demands brought about by the proliferation of advanced telecommunications. World-class research has led to advanced equipment and techniques in this area. Already, solar arrays dot isolated Marine outposts and ONR and the Naval Research Laboratory are working on a next-generation solar blanket. These flexible panels promise significant gains in both portability and efficiency.

Marine Corps water transportation hasn't changed much over the years. (Shown 1952, 2012.)

Another example of current research in energy scavenging is the Lightning Pack concept, developed by Dr. Larry Rome of the University of Pennsylvania, which harnesses the kinetic energy of a pack bouncing up and down on a Marine's back to generate electricity, which is used to charge batteries or power radios. When the Marine is stationary, hand-pumping the mechanism serves the same function. Now a Marine Scout Sniper team can occupy a hide for 96 hours without dozens of excess batteries. Such advances are critical in returning Marine Corps combat units to their expeditionary roots.

Increased self-sufficiency offers other benefits as well. Centralized power generation creates great quantities of heat. The coordination between distributed units and their logistics support floods the airwaves, and few endeavors are less subtle than a large convoy navigating the battlespace. Across the electromagnetic spectrum, our activities and intentions are made clear to the enemy through our efforts to merely sustain operations. When the United States faces a peer or near-peer adversary, this large signature will become problematic. Energy scavenging offers the promise of distributing and reducing that signature.

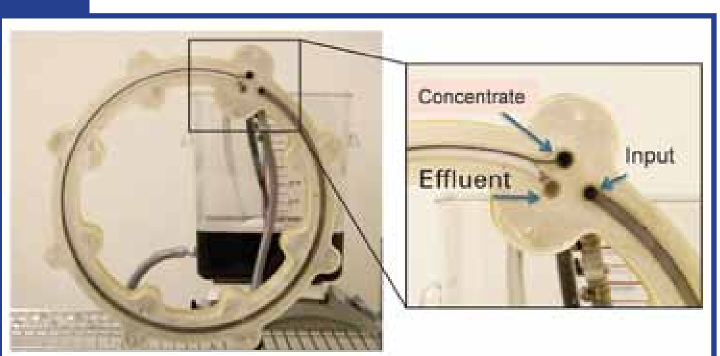
With this in mind, I want to discuss the idea of treating energy not as a mere flow of electrons, but as more of an abstract concept. Consider a unit of water; it represents a unit of energy. Without getting into the equivalence of mass and energy, think about the impact of water on the individual Marine. Marines use water as a catalyst to heat our Meal Ready-to-Eat or MRE. We use evaporation to cool us in the form of sweat. When a Marine walks up a hill with water in his pack, he changes its potential energy. And how do we get water to Marines? We truck it all over the battlespace, sling-load it to CH-53s to drop it at remote positions. In Afghanistan, it comes packaged in water bottles, purchased throughout the Middle East and Asia. The answer is it takes energy to get there. Humans can live without power for a few days but a couple days without water means certain death. Water is an incompressible fluid, and unlike electricity, the weight is in the commodity, not in the packaging. A new ultracapacitor may be developed that stores more electricity in a given package (it's being worked on), but geometry has placed well-defined limits on the packaging of water. Considering these challenges, it makes sense for energy scavenging efforts to really investigate the potential of scavenging water.

Many efforts are currently in the works: from the Basic Research that will provide the foundation for future advances, to Advanced Technology that is on the cusp of providing deployable systems. Sensor Electronic Technology Inc (SETi) of Columbia, SC is advancing work that uses both advanced filtration and UV-disinfection to render water safe to drink, even if the source contained biological agents. This is done through the destruction of the bacteria's DNA. BAE Systems,

This tight formation of 1L water bottles represents a week's worth of water for a Company of Marines.

meanwhile, is developing an energy-efficient desalination process, to address the challenge faced by Marines with so much of the world’s water being salty or brackish. The technology seeks to achieve sufficient loading of a thermodynamically driven ion capture agent on a high surface area substrate, allowing salt ions to be absorbed from the water using virtually no energy.

Cascade’s flat filter prototype is designed to fit inside the Camelbak system already carried by Marines.



PARC uses Hydrodynamic Separation (HDS) technology to separate particles from water without using filtration.

On the level of the individual Marine, Cascade Designs in Seattle is working on a flat-filter to be placed in Camelbak water reservoirs. This novel system would allow Marines to pour water from a stream directly into their Camelbak, while drinking safe, filtered water directly from the tube. The physical strain of carrying multiple gallons of water can be eliminated in a system whose functioning is completely transparent to the Marine.

Other less conventional methods are also being explored. The Palo Alto Research Company (PARC) is using hydrodynamic separation technology (HDS) to separate unwanted particles from water using a mechanical approach. Essentially, water is subjected to a centrifugal force in a curved channel, inducing transverse flow in the form of counter-rotating Dean vortices. Under correct conditions, this mechanism can isolate particles to a certain area of the flow, where they can be removed efficiently. Energy-intensive methods of pre-filtering water might be rendered obsolete by this technology.

The bad news is that we’re picky with our water, demanding a level of purification that can only be achieved through energy-intensive processes. But the efficiency of these processes, through some of the ground-breaking work described here is making the advantages of point-of-use water purification undeniable. The good news is that since water is essential for human survival, as long as Marines are fighting humans, we will be fighting in an environment with accessible water. In fact, look for the military forces to capitalize on advances in variable-angle drilling made by the petroleum industry to further capabilities in accessing groundwater in certain environments.

The time has come to start seeing water as the energy it represents. The future of the Marine Corps as an expeditionary force is contingent on finding the energy we need to fight in the same environment we do the fighting. After all, the ultimate goal of expeditionary logistics is to not need logistics at all. Technology solutions are on the way to help us achieve this goal. ■

INTEGRATED TOPSIDE

DYNAMIC CONTROL OF THE RF SPECTRUM IN FUTURE BATTLESPACE

Ms. Betsy DeLong – ONR Program Officer, Integrated Topside, Innovative Naval Prototype Program

INTOP will address the growth of RF systems that has resulted from independent development of topside systems. Currently each communication, EW, Radar function is developed independently and then 'compete' for space on an ever more constrained topside (some ship classes have seen their topside antenna count double in the last decade). The end result is after spending millions to optimize a system for a specific function we spend millions sub-optimizing it to work in the constrained/contested EMI environment we face. INTOP is taking a systems-of-systems approach to meeting all RF requirements for a platform that treats RF as a resource to be assigned to highest priority needs on a continuing basis. The INTOP vision is to provide the capability to dominate the EM spectrum through the flexibility of adaptive wide-bandwidth apertures & signal processing and provide significant total ownership cost reduction by having the same Radar/EW/IO/Comm components scale across platforms through modular, open architectures.

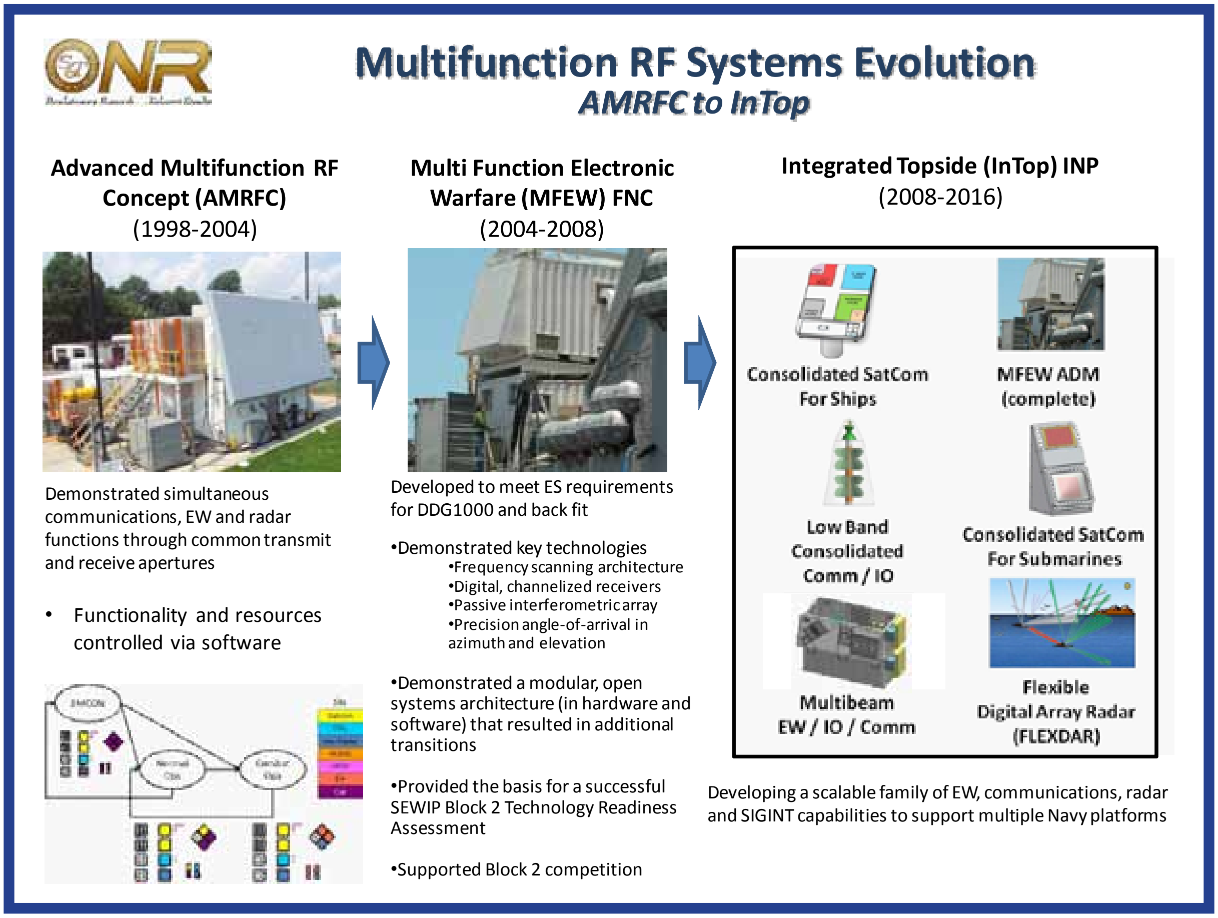
Overall INTOP objectives are:

- To demonstrate (in spirals) integrated, multi-function, multi-bean topside aperture construct that integrates communications, electronic warfare and Radar functions;
- To enable dynamic management of RF spectrum to instantaneously meet highest priority needs at any given time while meeting overall platform RF requirements;
- To provide more capability per ship through optimized aperture placement and space/weight/power improvements;
- Allow new CONOPs for operating within RF spectrum by monitoring to control EMI and increase RF availability.

INTOP will use an open RF architecture (hardware & software) that will:

- Be scalable to meet multiple platform needs (forward fit and back fit and reduce total SDD cost across these platforms);
- Allow common maintenance, training and logistic pipelines across platforms with attendant reduced vs. numerous stove-piped program O&S costs;
- Facilitate best of breed technology, competition and cost effective upgrades for apertures and electronics.

Game Changing Capabilities for Operating in the Electromagnetic Spectrum.



The INTOP program is based on:

- a successful demonstration of an open architecture (with 5 industry partners) multi-function, multi-simultaneous beam transmit and receive apertures that operated from 6-18 GHz and performed communication, electronic warfare, and radar functions directed by a RAM at NRL CBD;
- a successful S-band receive aperture that demonstrated on USS Lake Erie three simultaneous beams for standard missile telemetry and national asset download at a cost of less than the dishes that would otherwise be needed;
- numerous on-going solid state electronic component technology development efforts as well as innovative aperture architectures to reduce cost (it can be said that the biggest technical challenge INTOP faces is an affordable wide-band array);
- a successful demonstration of a scalable and open architecture with the Multi-Function EW (MFEW) program that transitioned to SEWIP Block 2;
- a nine-month Navy-Industry effort (10 companies participated) that collaborated to determine ‘best practices’ for RF Open Architecture design and minimum requirements to enable future upgrades for all INTOP prototypes.

INTOP UPDATE

During FY12, Northrop Grumman Corporation began the build phase for INTOP's multibeam Electronic Warfare (EW)/Information Operations (IO)/ Line of Sight Communications (Comms) Advanced Development Model (ADM). Raytheon also began building a Transmit Integrated Microwave Module in order to buy down risk by demonstrating specific high risk areas such as amplifier power output and cooling. Final designs were completed for the Wideband Submarine (Sub) Satellite Communications (SatCom) Antenna, production was begun, hydrostatic testing was completed and a test readiness review was held for the transmit array. The government team continued to refine the system architectures for the Consolidated Shipboard SatCom system, the Flexible Distributed Array Radar (FlexDAR) and the Low-Band RF Intelligent Distribution Resource (LowRIDR). During FY13, the EW/IO/Comms ADM will continue to be built and integrated and subsystem and full system tests and demonstrations will be performed to prove out the maturity of the various technologies. The EW/IO/Comms ADM will transition to the Surface Electronic Warfare Improvement Program (SEWIP) Block 3. The Wideband Sub SatCom Antenna will continue production for delivery to the Naval Undersea Warfare Center in FY 13 and transition to the Advanced High Data Rate (AdvHDR) program. INTOP will continue to develop the Consolidated Shipboard SatCom System, FlexDAR and the LowRIDR in FY13. A contract to build the front-end subsystem for FlexDAR is planned for award in FY13. The back-end subsystem development will be completed by a government team and is also planned to begin in FY13. A contract to provide systems engineering and integration and test support to the government for the LowRIDR ADM is also planned for award in FY13. The selected contractor will work with the government team to continue developing a notional system architecture and requirements for the LowRIDR ADM. ■

System-of-Systems Approach to RF Sensor and Communication Requirements.

THE FUTURE OF ELECTRO-OPTICAL/INFRA-RED SCIENCE AND TECHNOLOGY IN THE NAVY

Ron Driggers, Ph.D. – Naval Research Laboratory

Navy Electro-Optical/Infra-Red (EO/IR) problems are substantially different than those in the other services. Service EO/IR needs are largely defined by the comparative operating environments of each service. The Army fights predominantly on land with an atmosphere that can be clouded by dust, smoke, and other obscurants, and with most engagement distances defined by the horizon and terrain to be a handful of kilometers. Those factors drive the Army to use primarily longwave infrared (LWIR) sensors that enable them to see through smoke, handle hot burning targets without saturating, slew around quickly without motion blur, and see in extremely cold environments without being photon starved. Current Army advanced sensors are multi-wavelength incorporating shorter wavelengths for improved resolution and improved autonomous operation. The Navy, on the other hand, operates in a maritime environment that transmits midwave infrared (MWIR) better than LWIR. Also, the Navy generally has much longer engagement distances than the Army. Since MWIR sensors provide longer detection and identification ranges compared to LWIR sensors with the same aperture, the Navy currently operates predominantly MWIR sensors to fulfill its missions. The Navy also uses shorter wavelength sensors for improved resolution and autonomous processing.. All imaging sensors, whatever the wavelength, strike a balance between the parameters of the area that is imaged, the spatial resolution in the image, how often the area is imaged, and multi-wavelength operation. The tradeoff amongst these parameters naturally varies with the Navy mission and the operating environment. The Air Force operates in airborne standoff and some close support conditions.

The future of EO/IR Science and Technology in the Navy can be examined in three areas: sensors for ships and submarines, sensors for aviation, and sensors for the Marine Corps. Sensors for ships and submarines are currently following the MWIR long range targeting (target detection and identification) trend of sensors with several fields of view including one with very high magnification to provide the longest possible identification range and a lower magnification one for a wider angular field of view (usually on the order of a few tens of degrees) for initial target detection. In a maritime environment, Navy ships really need situational awareness around the full 360 degree horizon and recent work is leading to panoramic sensors that can monitor contacts all the way around the platform. One such sensor, shown in figure 1, is under development by the Office of Naval Research (ONR) and the Naval Research Laboratory (NRL) for submarine masts.

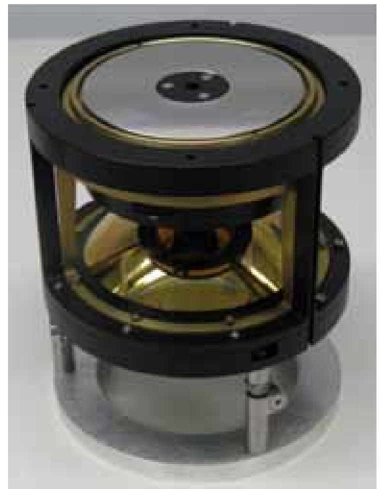


Figure 1. Submarine Panoramic Infrared Imaging Sensor (SPIIR).

Figure 2. Blue Devil Night Time Persistence Surveillance System.

This sensor has a unique toroidal optical design that provides a 360 degree field of view in the azimuth direction and +30 to -10 degree field of view in the elevation direction. ONR and NRL are developing a similar panoramic system for shipboard use that incorporates a larger imaging sensor and that will provide 24,000 pixels on the horizon for detection and tracking of small targets. Once a target is detected and tracked, a high magnification, ultra-narrow field of view sensor can be "slewed" to point in the direction of the target to identify it and determine whether it should be engaged. This procedure is sometimes called "slew to cue," and an area of active research is automating this process as much as possible. The goal is to develop the capability to automatically analyze the imagery from the wide angle sensor to detect targets, pass the target track to the high magnification field of view sensor, and analyze its imagery to classify or identify the target and then and only then bring a person into the loop. Automating image processing to free Navy personnel from the mind-numbing task of scanning imagery 24/7 is a theme that is common to all Navy EO/IR areas and DoD in general.

For aviation systems, the historic performance balance has been between the visible portion of the spectrum (high spatial resolution, poor haze penetration, daytime only, large pixel count cameras, ambient temperature operation) and the MWIR or LWIR (much lower spatial resolution, excellent haze/smoke penetration, day/night operation, smaller pixel count cameras, cryogenic operation). Recent developments in shortwave (SWIR) imaging promise to break that logjam for the task of target acquisition. The SWIR systems provide spatial resolution that is close to that in the visible with far better haze penetration. They operate at ambient temperature and have limited night time capability in addition to excellent day time performance. With the promise of some commercial markets, the pixel counts in SWIR cameras are also increasing rapidly. The other aviation mission of Intelligence, Surveillance, and Reconnaissance (ISR) has recently developed a second mode of operation. The traditional ISR mission has been to acquire imagery as fast as possible, over as large an area as possible, with as high a resolution as possible. The conflicts in the Middle East have led to the development of Persistent-ISR (PISR) as a second ISR mission. In this mode, the imagery is acquired continuously, hopefully 24/7, but over a fixed area such as a portion of a city. In addition to real time analysis to detect hostile activity, this imagery is stored and has enabled the forensic backtracking of suicide bombers, vehicle bombs, and improvised explosive device to their origins. The Blue Devil night time system shown in figure 2 is a manned aircraft version of PISR. The future should see the PISR mode applied to the maritime environment for wide area coverage and tracking of maritime entities in critical, high traffic areas such as Straits of Hormuz and Malacca. The future should also see multi-mission sensors that combine all three sensing modes target acquisition, ISR, and PISR on the same platform and in the same turret. These sensors will be essential for littoral missions, border patrol, and operations in the pacific and critical areas such as those already mentioned.

Other technologies that will be realized in the near future are three-dimensional mapping sensors using laser radar, geo-registered multiple imaging modes, and multiple intelligence sensor fusion. The use of Signals Intelligence (SIGINT), Synthetic Aperture Radar (SAR), and EO/IR all in cooperation has been demonstrated for various missions with great success. In the longer term for aviation are smaller detectors, higher operating temperatures, multipurpose, and multi-INT systems. In addition, sensors will work together with fully autonomous operation. Information from the platform is desired instead of data from the platform. Platforms will be making decisions and taking action. We expect to see intermediate range platforms disappear and more emphasis will be placed on high performance, long range, standoff systems as well as cheaper, shorter range, organic systems.

EO/IR Science and Technology for the Marine Corp is a mixture just as the Marine Corps missions mix ground combat similar to that of the Army while Marine Corps aviation includes both fixed wing and rotary wing platforms. Just as the ground based systems will in many cases follow directions similar to that of the Army, the aviation component will follow the trends discussed above. One addition, primarily for rotary wing platforms, will be the near term development of advanced IR sensing, possibly coupled with acoustic sensors, for Hostile Fire Indication (HFI) and also the determination of the origin of the hostile fire. Another area with a great deal of activity is the development of remotely controlled weapons. These will require wide and narrow field of view EO/IR systems to provide panoramic situational awareness and high resolution identification of targets. Since the Marine Corps is a highly mobile force, all these systems must be less expensive with smaller size, weight, and power consumption while maintaining full capability.

It is an exciting time for EO/IR in the Navy and Marine Corps. In the past few years, LWIR detectors have decreased to 5 micrometers in dimension and MWIR detectors now operate anywhere from 130 to 150 Kelvin. Gradient index optical materials are now produced in the SWIR to provide higher performance lens systems with smaller size and lighter weight. Analogous new materials will soon be achieved in the MWIR and LWIR. LWIR sensors based on bolometric detection and operating at ambient temperatures are becoming more sensitive, with higher pixel counts and better resolution. They will begin to find their way onto Navy and Marine Corps platforms for shorter range applications which have a different balance point between cost and performance. New laser materials are achieving higher power at room temperature every few months and optical fibers are now successfully transmitting high power laser light in the MWIR. Sometimes, it seems difficult to keep up with all the technical progress, but you can be assured these materials and components will affect a huge range of Navy systems and how they operate. ■

DIRECTOR'S CORNER

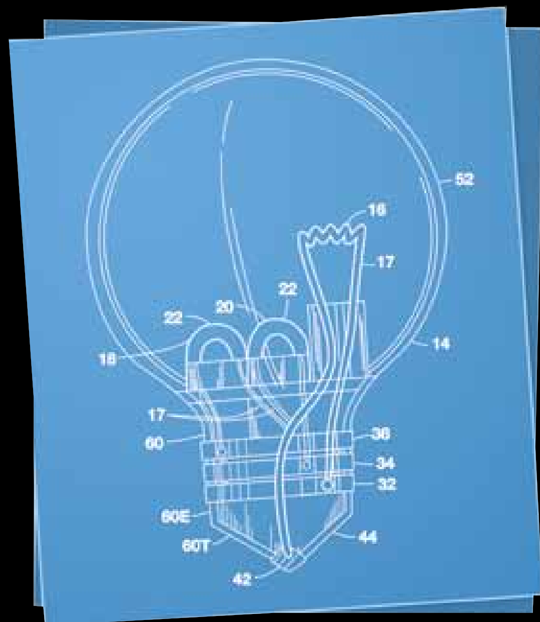
DOMINATING THE ELECTROMAGNETIC SPECTRUM

Lawrence C. Schuette, Ph.D. – ONR Director of Innovation

The theme of this issue is "Dominating the Electromagnetic (EM) Spectrum." Since the early 20th century the electromagnetic spectrum has become increasingly important; first for communications and later for long range sensing. During the Russo-Japanese War (1904-1905), just a few years after its invention, wireless communication were used by both combatants. The first recorded use of "Electronic Attack" occurred at the Battle of Tsushima when Japanese radio operators successfully jammed Russian communications with their transmitters. This would become the first of many in-the-field innovations by electronic warfare specialists. Fast forward to the 1930s just prior to World War II when the German Zeppelin LZ-130 was flown on electronic intelligence missions against the British Home Chain radars. The LZ-130 is remembered for several electronic warfare and radio interception missions over the English coast.

Today the Electromagnetic Spectrum is "DC to Daylight" or continuous coverage, an even more critical enabler. The public and military use of the EM spectrum continues to grow and thus ONR's interest in this area also continues. ONR sponsors research in basic science such as graphene and gallium nitride. We are also working to develop new electronic devices that have increased performance. Our flagship EM effort is the Integrated Topside (INTOP), an ONR Innovative Naval Prototype, which you read about earlier in this edition of the ONR Innovation Newsletter. This effort, being worked by ONR, Program Executive Office Integrated Warfare Systems, Navy Labs and our Industrial partners, leverages our electronic, Radar and communications research to create a revolution in electronic warfare, communications and radar. No longer will platforms be required to add additional apertures each time a new system is brought on board. Rather, the requirement will be met by a shared resource. This open architecture hardware and software model provides dramatically increased performance with great flexibility. This revolution is permeating across our efforts as we have learned that to innovate within the DOD acquisition process requires a new way of thinking. ■

NRL invented, developed, and installed the first operational U.S. radar, the XAF, on the battleship USS New York in 1939. It was rapidly transferred to industry for production. By the time of the attack on Pearl Harbor, 20 radar units were in operation. Radar of this type contributed to the victories of the Coral Sea, Midway, and Guadalcanal. PHOTO CREDIT: Naval Research Laboratory.



INNOVATION

BEYOND IMAGINATION™

Lawrence C. Schuette, Ph.D.
Director of Innovation
tel: 703-696-7118
fax: 703-696-4065
email: larry.schuette@navy.mil
schuetl@onr.navy.smil.mil

Craig A. Hughes
Deputy Director of Innovation
tel: 703-696-3039
email: craig.a.hughes@navy.mil

Office of Naval Research
One Liberty Center
875 North Randolph Street
Suite 1425
Arlington, VA 22203-1995
www.onr.navy.mil/innovate