# Spectrum Monitoring for the Fleet

*By Jonathan Vick, Jeff Acree, and Bruce Naley*

## Interference Problems

The same story plays out time after time. Be it from a cable TV or cellular phone provider, or even a formal protest from a foreign country—another accusation of radio frequency (RF) interference attributed to a U.S. Navy system is again reported. The U.S. Navy and its powerful radars and communications systems are constantly on the move and occasionally interfere with other spectrum users. In the early 1990s, chronic Navy to commercial radio frequency interference (RFI) problems in the Caribbean climaxed with a Navy training exercise being accused of ruining most of a Superbowl broadcast for the entire island of St. Thomas. After that, a permanent banner appeared on St. Thomas Cable to inform the public that ANY picture quality issues were likely due to the U.S. Navy and complaints should be directed thereto. This obviously created problems and a great deal of additional work for Navy leadership. At other times, the Navy is its own victim, with one unit interfering with another.

The Navy develops and uses detailed frequency plans that direct all the frequencies and channels each Navy system should use. These plans are optimized by the Afloat Electromagnetic Spectrum Operations Program (AESOP) to reduce or eliminate interference. However, sometimes either the plans are not followed, operators make ad hoc "modifications" to plans due to equipment casualties, or the plans are not updated as the situation changes.

Ships are not the only naval assets that have to deal with RF interference issues. Consider test ranges like the Pacific Missile Range Facility (PMRF) that tests ballistic missiles. These are very expensive and potentially dangerous tests. Quite a lot depends on the RF commands and telemetry between the missile and the ground controllers operating properly, especially the special frequency and command set used to self-destruct the test missile if something goes wrong. Even though test sites are chosen for their remoteness, there is always the potential for some amount of commercial or pleasure boat traffic in the vicinity. Then, there is always the possibility that with all the different test facilities on site, some of their own emitters might be turned on accidentally.

Currently, the Navy is ill-prepared to defend itself when falsely accused of interfering with civilian commercial interests. In the above Caribbean example, word of Navy interference spread to other services beyond cable TV providers—even in frequency bands where the Navy was not operating. In the absence of a robust means to police the spectrum, it took too long to locate interference sources and then determine and prove the Navy's innocence. Because it could not prove otherwise, the Navy became the scapegoat for all electromagnetic interference problems in that part of the Caribbean, whether caused by the Navy or not.

As a result of these types of incidents, a number of questions surfaced, such as: How can the Navy police itself to ensure compliance with its own frequency plans and protect itself and others from Navy-created interference? How can the Navy protect itself from RF interference caused by others? How can the Navy prove to others what it is and is not transmitting? In answering these questions, the first step is ensuring that the Navy is aware of all (i.e., self-generated and third party) RF emissions in the environment. In a phrase—spectrum monitoring—should occur, with the goal of identifying and addressing frequency conflicts before any system degradation occurs or, at a minimum, very shortly after it is reported.

The goal of spectrum monitoring reflects the intent of the Department of the Navy's (DON's) electromagnetic spectrum policy.[1] It states:

- The DON shall continually strive for efficient spectrum use.
- The DON must ensure that available spectrum is efficiently utilized to provide the greatest benefit to the overall DON mission.
- The DON shall apply sound engineering and administrative practices throughout the Department to ensure effective and prudent use of electromagnetic spectrum.
- The DON should maintain its pre-eminence in identifying and evaluating new techniques for efficient spectrum use that could potentially benefit the Navy and/or the Marine Corps.

Not only do these mandates require that each emitting system be spectrally efficient, but when many systems are operating in close proximity, their use must be coordinated to ensure that the overall spectrum is being used to the maximum benefit of the Navy mission. If one system interferes with the spectrum another system is using, or is assigned a frequency where third party interference exists (when perhaps an alternate usable frequency is available and interference-free), then the total available spectrum is not being used efficiently. Having an optimized frequency plan and a means to verify its implementation, enforce its use, and adjust when needed is one way the Navy can adhere to the precepts of the SECNAV policy.

NSWC Dahlgren has been leading Navy spectrum sensor development and implementation efforts since the early 1990s. In spectrum classes that NSWC Dahlgren provides to all prospective ship commanding officers, many have inquired as to why the Navy doesn't have a method to help them enforce their frequency plans and identify interference. They have expressed a sense of helplessness in being able to ensure that their plans are being followed to keep their systems interference-free. To this end, NSWC Dahlgren's Spectrum Engineering Group embarked on an effort to support the development of spectrum monitoring systems for the Navy, with the ultimate goal of providing an automated feedback loop that will alert a Navy frequency manager when its own frequency plan is not being followed or when an unexpected RF emission poses a potential conflict.

## The Spectrum Monitoring Solution

Currently, a joint project between the Dahlgren's Spectrum Engineering Group and the commercial firm Argon ST is underway to develop a system called the True RF Environment Extractor, or T-REX for short. T-REX is the first step in the quest toward an automated spectrum monitoring system. T-REX will:

- Continuously scan frequency ranges of interest (currently limited from 0.5 GHz to 18 GHz)
- Identify and log each detected RF emission's characteristics
- Compare each signal's characteristics to an emitter list
- Identify the source if there is a match
- Generate a track for each newly detected emission

Although not yet automated beyond this point, an operator interested in a particular emission could then further analyze it and use the system's spinning direction-finding (DF) antenna to determine a bearing to the source. When multiple systems are operating in proximity, the detected signal can then be triangulated, and the exact location of the source determined. The T-REX operator also has the capability to compare tracks to Automatic Identification System (AIS)-based geolocation data for platforms that are properly equipped. These capabilities, as well as others, are planned for automation in the coming years.

The T-REX system includes a complete complement of equipment to perform RF signal intercept, processing, analysis, classification, and data reporting. The system consists of commercial off-the-shelf (COTS) equipment and runs on Microsoft's Windows XP operating system. It is organized into three functional groups, including the main mission antenna (MMA) assembly (see Figure 1), the remote location equipment (receiver assembly) (see Figure 2), and the operator workstation (see

Figure 3). These components are connected with other add-on components, such as a Global Positioning System (GPS) time receiver, to complete the T-REX Remote Site System (see Figure 4).

The MMA consists of a 0.5–18 GHz antenna assembly, with both omnidirectional and high-gain spinning DF elements, which are both contained in environmentally protective radomes. In shipboard installations, the MMA would be located topside on the mast or ship superstructure, and for land applications, on a tower or other high point. The remote location equipment consists of an RF distribution component, microwave receiver, coherent signal processor (CSP), digital pulse analyzer (DPA), and an electronic support measures (ESM) processor. This latter subcomponent will need to be located inside a structure within proximity of the antenna. The operator workstation consists of a processor with keyboard, trackball, and dual flat-panel displays. The subsystem provides the user with a user-friendly Microsoft Windows-based software application interface that enables the operator to monitor the full RF bandwidth, build a prioritized scan strategy to maximize probability of intercept for signals of interest, display the detected spectrum, or perform detailed analysis on signals of interest using the digital pulse analyzer. An example screen display is shown in Figure 5.

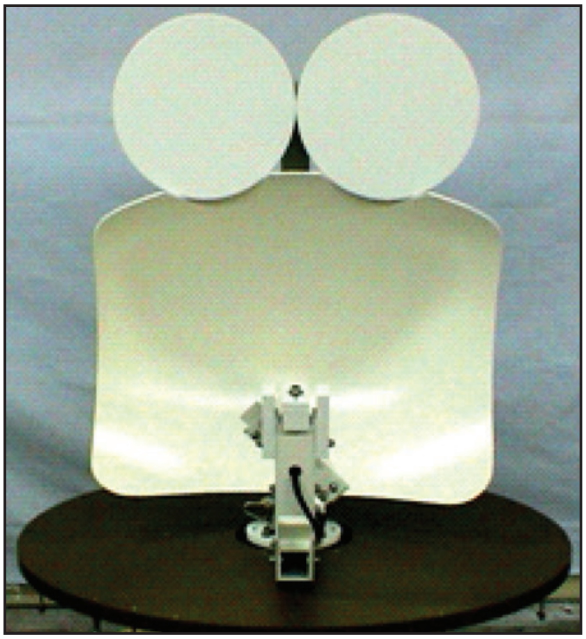


**Figure 1.** Main Mission Antenna (DF)

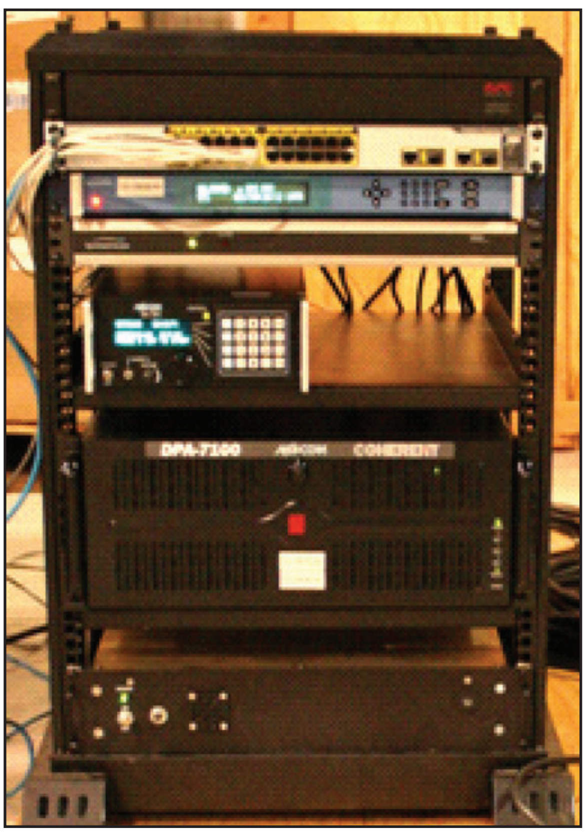


**Figure 2.** Remote Location Equipment

**Figure 3.** Operator Workstation

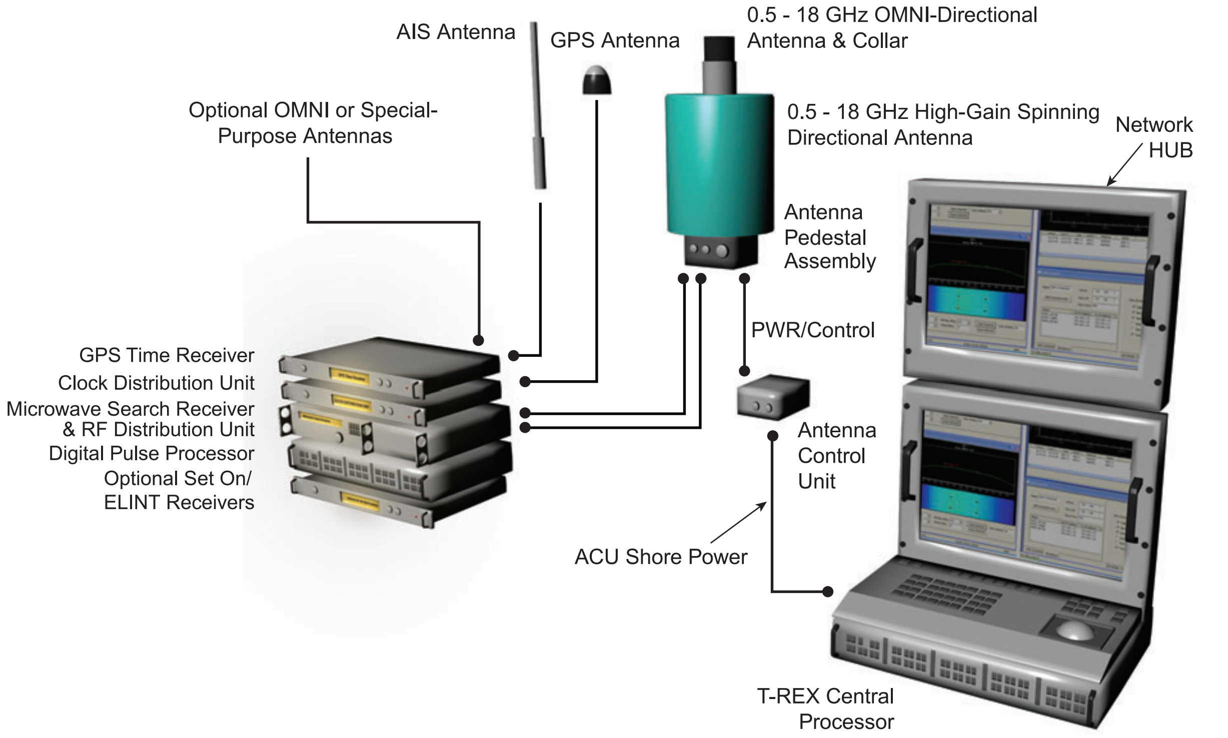



**Figure 4.** T-REX Remote Site System Components

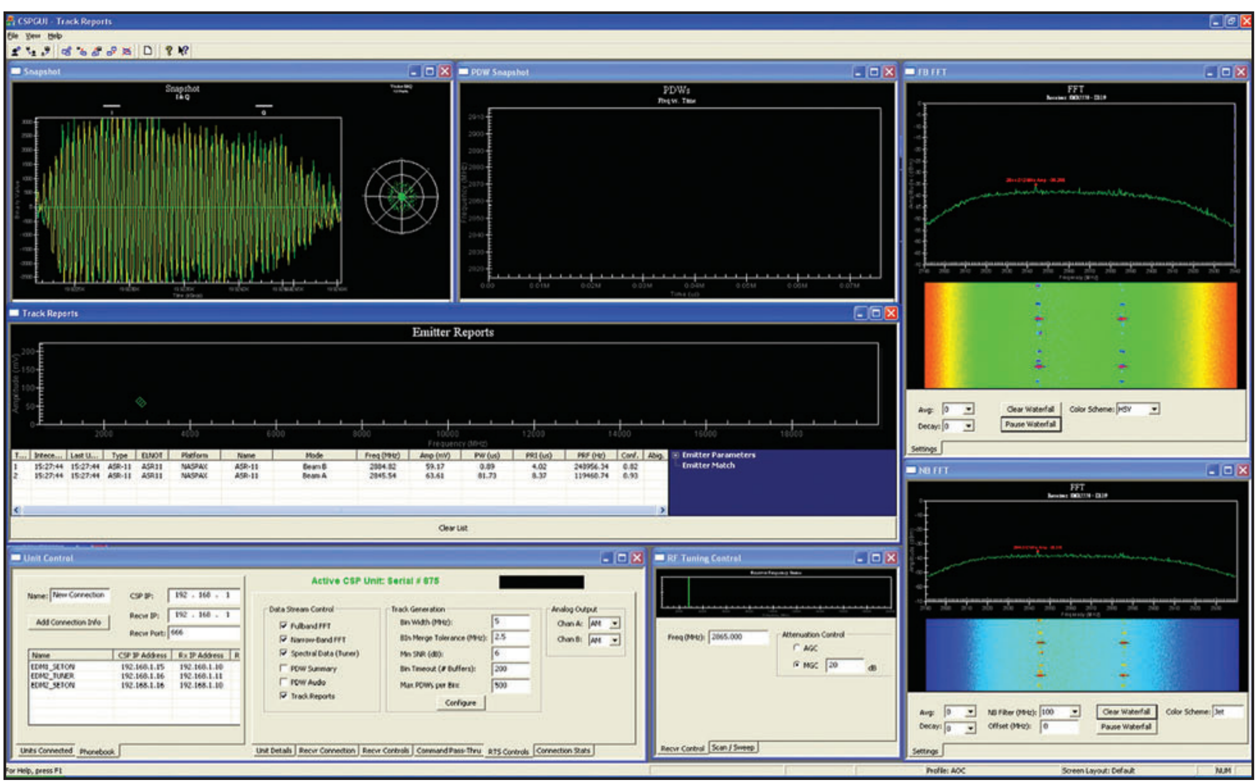



**Figure 5.** T-REX Operator Workstation Screen Display

Currently, the T-REX system is installed and being evaluated at NSWC Dahlgren. To minimize the time and cost associated with first article testing, the prototype T-REX system will undergo stringent testing to evaluate system performance and determine reliability prior to deploying the system to PMRF. Dahlgren's proximity to active waterways enables testing of all system components in live situations in addition to simulated test cases. The T-REX evaluation should be completed by the second quarter of FY09, with deployment to PMRF immediately following (see Figure 6).

## The PMRF "Testbed"

A test location for the T-REX system was needed that would allow all of the system components to be utilized and challenged in an active Navy environment. To meet this requirement, the PMRF was chosen to house the initial test deployment of T-REX. Given PMRF's existing interest, infrastructure, and their Navy mission, they exemplify the perfect place to test the first prototype T-REX system.

PMRF is the world's largest instrumented multi-environment range and the only one in the world capable of supporting surface, subsurface, air, and space operations simultaneously. NSWC Dahlgren has been working with PMRF for many years, providing technical expertise concerning their spectrum needs. PMRF has been proactive in spectrum management and hopes to upgrade its capability in the near term. They expressed a strong interest in an automated spectrum monitoring system and ultimately would like to strategically outfit several Navy sites in the Hawaiian Islands to build a networked "Spectrum Monitoring Grid" that can be operated from a single control point. The goal is to fuse collected data from all the sensors to provide a seamless spectrum picture of the covered region.

The initial installation of the T-REX system will be dual-purpose, with PMRF gaining the benefit of the system in its current configuration to support their range activities, while at the same time providing feedback to NSWC Dahlgren on system performance and suggested improvements. The installation location of the first T-REX system at PMRF will be on a small remote site at the highest point of Niihau, a small, privately owned island approximately 17.5 miles Southwest of Kauai, where the Navy leases a small plot for monitoring antennas. This is across the Kaulakahi Channel from the main PMRF site at Barking Sands on the west coast of Kauai. This location will give the T-REX antenna line-of-site coverage over the entire Kaulakahi Channel, where most of the ship and aircraft testing occurs, as well as north and west of Niihau to cover the flight paths of ballistic missile tests. The antenna

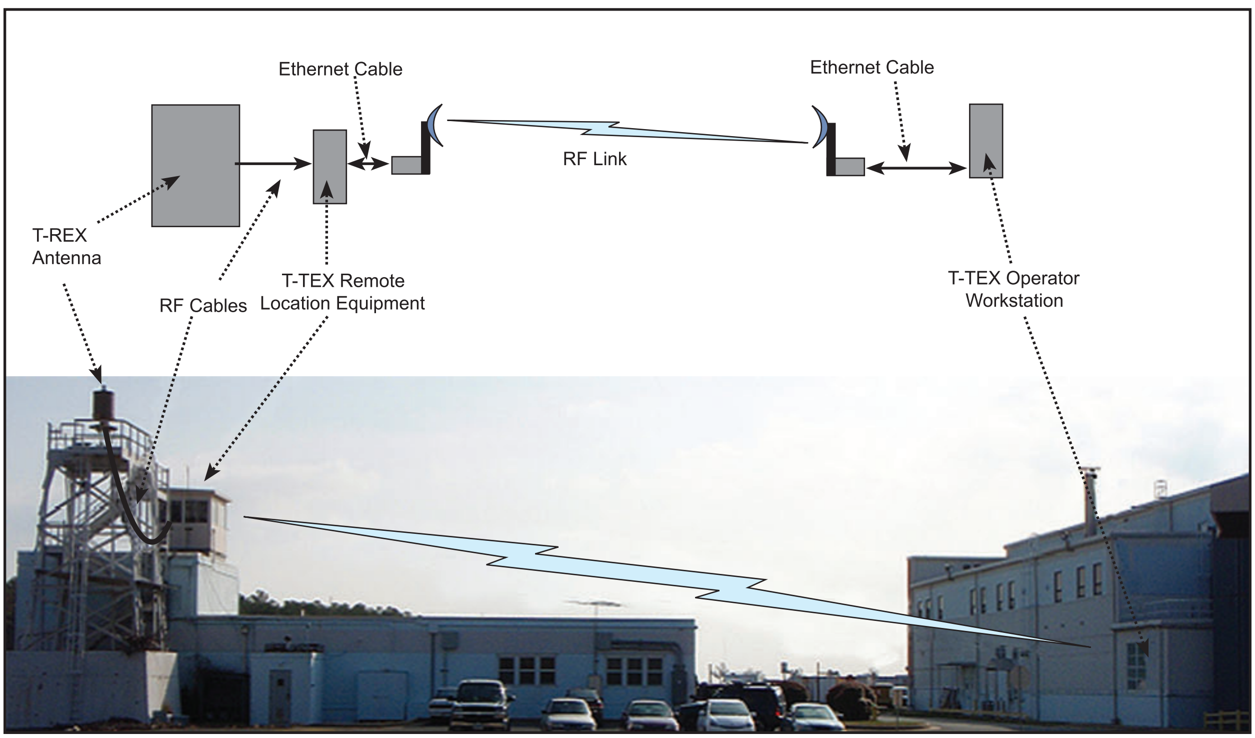



**Figure 6.** NSWC Dahlgren Evaluation Installation Prior to PMRF Deployment

will be mounted on a tower at the site, with the remote location equipment housed in a small-powered and air-conditioned equipment shelter. The operator workstation will be located at the PMRF frequency manager's control room at Barking Sands (see Figure 7).

The two T-REX equipment racks will be connected through a PMRF intranet local area network (LAN) that utilizes a dedicated microwave link between Kauai and Niihau. Additionally, since the PMRF frequency manager wants to be able to monitor and control the T-REX from multiple locations at PMRF, the requisite software and settings will be installed on several computers on the LAN so that any one of them can take over the role of the operator workstation and monitor and control the T-REX. Whether utilizing the operator workstation or any other properly configured computer, the user will control the T-REX by simply running remote desktop control software called Ultra VNC, taking over control of the processor on the remote location equipment rack that runs the T-REX software. Once the first prototype has been adequately tested and evaluated, with user feedback incorporated into design improvements, NSWC Dahlgren will deploy at least one or two more systems at PMRF to provide the ability for an operator to pinpoint any source or errant emission near their range through triangulation, and eventually, with further development, the full PMRF grid.

At the same time that the system is being evaluated at PMRF, NSWC Dahlgren programmers will be working on linking the T-REX system with the fleet standard AESOP frequency management software. Using extensible markup language (XML) file protocols, the detected spectrum output of the T-REX will be fed into the AESOP software for comparison to the current area's frequency plan. Automated user warnings will be generated when variations or conflicts are detected between the frequency plan and the T-REX monitored spectrum. PMRF would like to create frequency plans that include all the emitters expected to be active during a test and then receive warnings if and when undesired signals are detected. Once this phase is complete, the Navy will have the first version of a comprehensive, automated frequency management and spectrum monitoring system that will able to detect and locate spectrum conflicts in real time.

The planned spectrum monitoring grid for PMRF could accomplish all the trademark goals of a modern spectrum monitoring system. Future spirals could include emerging techniques such as highly accurate, multisite geolocation via JASA 2.0-compliant signal time-of-arrival measurements. Other capabilities, such as specific emitter identification and powerful electro-optic infrared (EOIR)-like tracking cameras are also possible upgrades for the system. The plan has a number of remaining hurdles and will require buy-in from key NAVAIR and NAVSEA stakeholders to move forward. If the T-REX system meets expectations and further development is supported, the Navy will benefit tremendously from this capability.

## Reference

1. SECNAV Instruction 2400.1, *Electromagnetic Spectrum Policy and Management*.

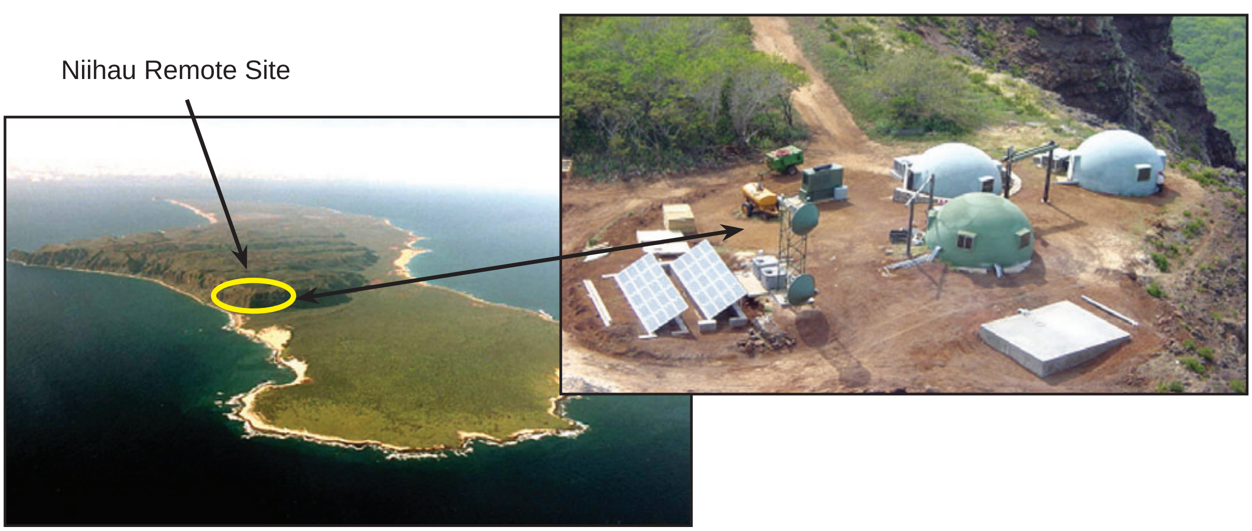



**Figure 7.** Niihau Remote Site Location for First T-REX Installation at PMRF

# NSWC Dahlgren's Role in the Navy's Spectrum Certification Process

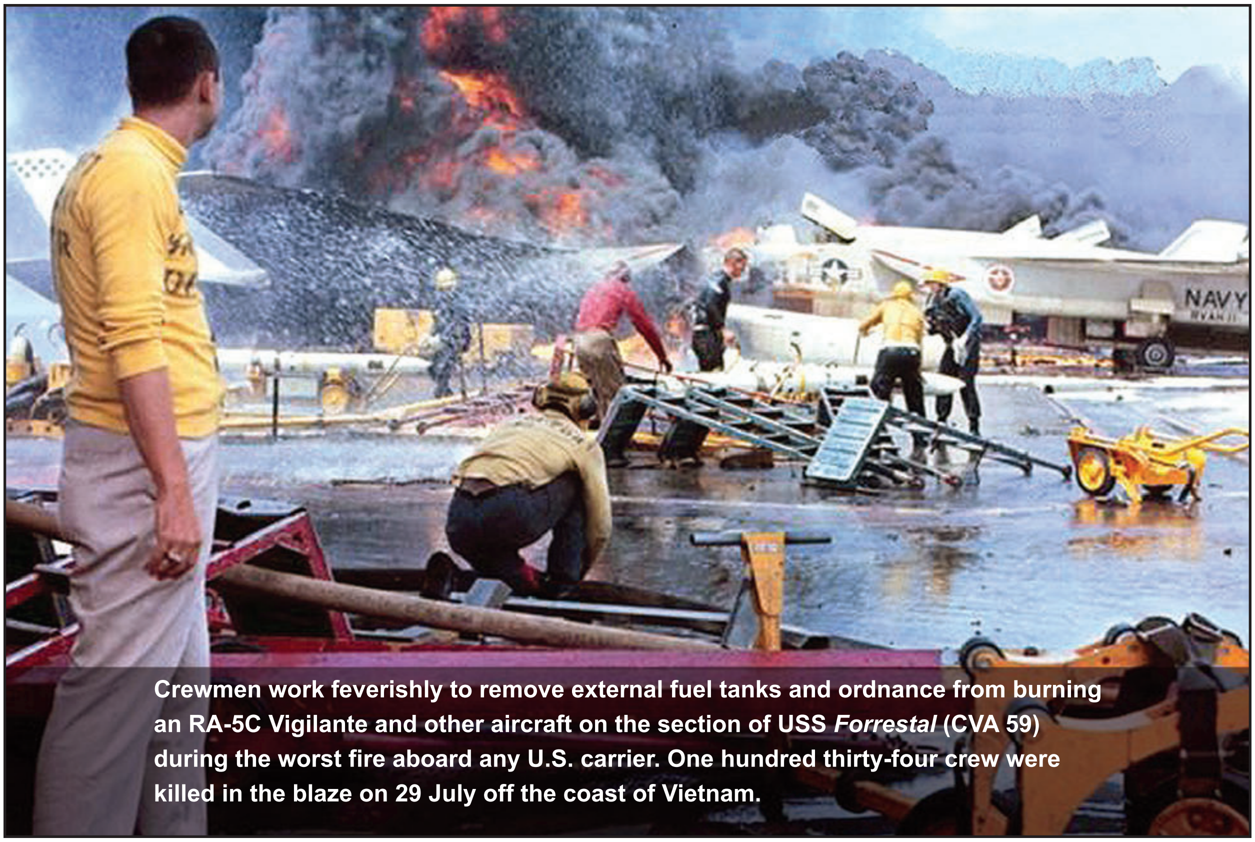
*By John Darden*

Imagine an aircraft carrier in the midst of retrieving and launching aircraft engaged in combat operations. The electromagnetic environment generates wandering electrical currents that ignite a rocket aboard an aircraft. The wayward rocket slams into another aircraft causing a fuel spill. The fuel ignites, and the resulting fire and exploding ordnance kill more than 130 personnel, injure many others, and destroy 26 aircraft (see Figure 1).

The incident just described actually happened. It occurred because the electromagnetic environment at the time was not given high priority. Fortunately, incidents such as this are far less likely to happen today due to the critical role that the Naval Surface Warfare Center (NSWC) Dahlgren Division plays in the Navy's spectrum certification process. NSWC Dahlgren has been at the forefront of investigating, analyzing, and implementing solutions concerning electromagnetic environmental problems since 1956.[1] Today, Dahlgren personnel perform testing and measurements of equipment and systems that utilize the electromagnetic spectrum both on-site and in the field. Using state-of-the-art test equipment and innovative testing techniques, scientists and engineers are able to provide detailed analyses of spectrum-dependent equipment and systems without impinging on equipment or system integrity or capability.

As a Naval Sea Systems Command (NAVSEA) Warfare Center activity, NSWC Dahlgren, through its Electromagnetic and Sensor Systems Department, E3 Force Level Interoperability Branch, Spectrum Engineering Group, provides support to developers and procuring agencies in obtaining frequency allocations for their equipment or systems. The branch works closely with project personnel, program office personnel, and vendors, together with unclassified and classified resources, to conduct research on the equipment or system requiring spectrum certification.

In compliance with National Telecommunications and Information Administration (NTIA) regulations and Department of Defense directives, the U.S. Navy implemented a policy regarding Electromagnetic Environmental Effects (E3) and Spectrum Supportability to manage the effects the electromagnetic environment has on operational equipment, systems, platforms, and forces. Spectrum supportability is defined as: "the assessment as to whether the electromagnetic spectrum necessary to support the operation of a spectrum-dependent equipment or system during its expected life cycle is, or will be available."[2] Accordingly, a spectrum supportability determination is mandated for all equipment and systems that utilize the



Crewmen work feverishly to remove external fuel tanks and ordnance from burning an RA-5C Vigilante and other aircraft on the section of USS *Forrestal* (CVA 59) during the worst fire aboard any U.S. carrier. One hundred thirty-four crew were killed in the blaze on 29 July off the coast of Vietnam.

**Figure 1.** Fire Due to a Runaway Rocket On Board the Flight Deck of USS *Forrestal*, July 1967

electromagnetic spectrum before proceeding into system development and demonstration (SDD) or production and deployment (P&D) phases of the acquisition process, unless specific authorizations or waivers are granted.

Equipment spectrum certification, alternately called spectrum certification, is defined as: "the statement(s) of adequacy received from authorities of sovereign nations after their review of the technical characteristics of a spectrum-dependent equipment or system regarding compliance with their national spectrum management policy, allocations, regulations, and technical standards." Spectrum certification is a subprocess in the spectrum supportability process. This process, also known as the J/F-12 process, begins by completing and submitting DD Form 1494, "Application for Equipment Frequency Allocation" (see Figure 2). After a sequence of steps that include multiple reviews, possible correction or revision, and approval of the application, a spectrum certification is granted, and a J/F-12 number is issued for the equipment or system.

If the data needed to complete a DD 1494 application is not available—as is often the case for commercial off-the-shelf (COTS) or foreign equipment—then the E3 Force Level Interoperability Branch performs measurements and tests as needed on the spectrum-dependent equipment. Members of the Spectrum Engineering Group conduct analyses on the measured data and provide test reports to document test procedures and techniques, data collected, and the underlying reasoning. Finally, the branch completes the application with the required data, whether measured or calculated, writes the cover letter and the foreign coordination letter if necessary, and submits the documents to the developing or procuring office.

Spectrum supportability of radio-frequency sensors in an environment that is shared with other sensors, communication devices, electronic warfare equipment, and a multitude of other spectrum-dependent devices falls under the purview of the Electromagnetic and Sensor Systems Department. This concentration led the department to establish a capability to support the spectrum certification

| APPLICATION FOR EQUIPMENT FREQUENCY ALLOCATION | CLASSIFICATION | DATE | *Form Approved OMB No. 0704-0188*<br>PAGE 1 OF PAGES |
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The public reporting burden for this collection of information is estimated to average 24 hours per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to the Department of Defense, Executive Services Directorate (0704-0188). Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.
**PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION. RETURN COMPLETED FORM TO THE USING AGENCY OR CONTRACTING AGENCY, AS APPROPRIATE.**

**DOD GENERAL INFORMATION**

| TO | FROM |
|---|---|

1. APPLICATION TITLE

2. SYSTEM NOMENCLATURE

3. STAGE OF ALLOCATION *(X one)*

☐ a. STAGE 1 - CONCEPTUAL ☐ b. STAGE 2 - EXPERIMENTAL ☐ c. STAGE 3 - DEVELOPMENTAL ☐ d. STAGE 4 - OPERATIONAL

4. FREQUENCY REQUIREMENTS
   a. FREQUENCY(IES)
   b. EMISSION DESIGNATOR(S)

5. TARGET STARTING DATE FOR SUBSEQUENT STAGES

| a. STAGE 2 | b. STAGE 3 | c. STAGE 4 |
|---|---|---|

6. EXTENT OF USE

7. GEOGRAPHICAL AREA FOR
   a. STAGE 2
   b. STAGE 3
   c. STAGE 4

8. NUMBER OF UNITS

| a. STAGE 2 | b. STAGE 3 | c. STAGE 4 |
|---|---|---|

9. NUMBER OF UNITS OPERATING SIMULTANEOUSLY IN THE SAME ENVIRONMENT

| 10. OTHER J/F 12 APPLICATION NUMBER(S) TO BE | 11. IS THERE ANY OPERATIONAL REQUIREMENT AS DESCRIBED IN THE INSTRUCTIONS FOR PARAGRAPH 11? |
|---|---|
| ☐ a. SUPERSEDED J/F 12/<br>☐ b RELATED J/F 12/ | ☐ a. YES ☐ b. NO ☐ c. NAvail |

12. NAMES AND TELEPHONE NUMBERS

| | | |
|---|---|---|
| a. PROGRAM MANAGER | (1) COMMERCIAL | (2) AUTOVON |
| b. PROJECT ENGINEER | (1) COMMERCIAL | (2) AUTOVON |

13. REMARKS

| DOWNGRADING INSTRUCTIONS | CLASSIFICATION | |
|---|---|---|

DD FORM 1494, AUG 96 PREVIOUS EDITION MAY BE USED. Adobe Professional 7.0

**Figure 2.** DoD General Information Page from DD Form 1494 "Application for Equipment Frequency Allocation"

process. The necessity for spectrum certification is manifold. Navy policy requires that spectrum certification be obtained as one of the requirements for spectrum supportability.[3] With the J/F-12 certification of equipment and systems, the data within the application documents provides the capability to evaluate equipment or system compliance with spectrum management policies, and national and international frequency allocations, regulations, and technical standards. Additionally, certification is required throughout the acquisition process as one of the requirements to achieve approval to transition to the next phase. Spectrum certification is also required for the procurement of nondevelopmental items (NDI) and commercial items such as COTS equipment or systems including Federal Communications Commission (FCC) Part 15 (low-power, unlicensed) devices. If the device requiring electromagnetic spectrum is to be used in a foreign country, then the required certification must be modified in order to obtain a Host Nation Frequency Authorization for foreign government authorization to operate the equipment within its jurisdiction. Recertification for equipment and systems previously certified must be performed when new frequency assignments are sought, modifications to radiation emissions are made, modes of operation are changed, locations of operation are changed, and so forth. Finally, a Stage 1 certification is required to obligate funds beyond the concept refinement stage to further research, develop, procure, or operate the equipment or system in question. Figure 3 shows a Dahlgren employee adjusting a spectrum analyzer.

An example of NSWC Dahlgren's role in the spectrum certification process was evident in the recent work performed in support of the Shipboard Warehouse Management System Local Area Network (SWMS LAN) aboard the dry cargo/ammunition ship USNS *Lewis and Clark* (see Figure 4). The LAN was to be used as a means of inventory control aboard the ship. The LAN was to be


**Figure 3.** An NSWC Dahlgren employee adjusts a spectrum analyzer—a tool used to perform a typical spectrum certification measurement.

**Figure 4.** NSWC Dahlgren performed measurements of the LAN aboard the dry cargo/ammunition ship USNS *Lewis and Clark*

implemented using multiple computers with wireless access, handheld scanners, and Wi-Fi access points. Spectrum certification of the system was mandatory due to the potential hazard of radiant electromagnetic energy in an enclosed environment with ordnance. The Spectrum Engineering Group performed measurements on the access points, tabulated acquired data, and wrote technical reports describing the test methodology and presenting the measured data necessary for a DD 1494 application. Work performed concurrently in other branches verified that the power levels due to the LAN and its other components met the standards for safe operation in close proximity to ordnance.

The goal of obtaining a spectrum certification can be a protracted process. The certification process should be initiated as early as possible in compliance with the requirements imposed for attaining milestones in the acquisition process. A partial list of the equipment requiring spectrum certification is as follows:

- Communications equipment
- Radars
- Transmitters
- Receivers
- Electronic Warfare (EW) systems
- Simulators
- Previously certified equipment that has been modified
- Test equipment
- Existing systems lacking certification
- COTS items
- Equipment purchased from foreign nations
- Global Positioning System (GPS) equipment

Items not requiring certification include electro-optics devices, nontactical and intrabase radios, and fuze development.

Successfully navigating through the process and obtaining J/F-12 certification ensures that the equipment, when granted an authorized frequency assignment, can be legally operated in the geographical location in which it is situated. Through this process, NSWC Dahlgren supports the overarching spectrum supportability process and ensures that scarce electromagnetic spectrum is available when the warfighter needs it, thus potentially saving lives, protecting materiel, and helping to ensure mission success.

## References

1. James P. Rife and Rodney P. Carlisle; *The Sound of Freedom: Naval Weapons Technology at Dahlgren, Virginia, 1918–2006*; U.S. Government Printing Office; NSWCDD/MP-06/46; p. 103.
2. OPNAVINST 2400.20F, Enclosure (1), dated 19 July 2007.
3. Ibid.

# Shipboard Electromagnetic Interference Problem Solving

*By Bradley Conner and Richard Soares*

## Introduction

Electromagnetic Interference (EMI) problem solvers from the Naval Surface Warfare Center, Dahlgren Division (NSWCDD) Electromagnetic Environmental Effects (E3) Force Level Interoperability Branch support the Naval Sea Systems Command (NAVSEA) E3 Technical Warrant Holder under the Shipboard Electromagnetic Compatibility Program (SEMCIP). With many high-power transmitters and sensitive electronic equipment collocated aboard naval vessels, electromagnetic compatibility (EMC) is an important role and responsibility of government engineers. Uncorrected EMI problems can severely degrade warfighting capabilities. EMI problem solvers are EMC engineers who provide initial response to urgent fleet requests for EMC assistance, perform characterization and quantification of EMI problems, identify solutions to mitigate EMI problems, and then evaluate their effectiveness. SEMCIP is the "honest broker" for the U.S. Navy by determining whether an EMI solution should best be installed on the source or victim system. EMI problem solvers must work closely with sailors and operating forces at the waterfront, program managers and in-service engineering agents (ISEAs) at the different warfare centers, and technology experts in industry. This article describes the steps necessary to solve shipboard EMI problems and highlights some of the success stories from current problem-solving efforts.

## Background

NSWCDD E3 Division strives to be the defense community's leader for ensuring mission success in the operational electromagnetic environment. One of the core competencies is EMI problem solving. There are inevitably EMI problems among the many high-power transmitters, sensitive receivers, and various other electronic equipment collocated in close proximity aboard naval vessels. Unlike shore-based facilities, there is usually not enough real estate on ships to move systems to noninterfering locations (see Figure 1). EMI problem solvers must step in and find solutions quickly and effectively, quite often without much advance warning.

Shipboard EMI is not a new problem. Out-of-band and other unintentional emissions degrade the function and operation of other onboard systems. Initially, EMI was caused by a lack of common knowledge concerning radio frequency (RF) characteristics by those who installed radios on ships and by those who operated them. As more and more transmitters and receivers were installed on ships, the EMI problems became more frequent, severe, and difficult to solve. In the 1970s, NAVSEA started a program called SEMCIP to manage these problems. SEMCIP continues to provide the U.S. Navy with prevention, identification, characterization, quantification, and correction of shipboard EMI problems affecting weapons systems, radars, communication links, and other electronic systems.

## Problem Investigation

SEMCIP desires to find and correct problems before the fleet experiences them. There is a great deal of analysis that happens upfront in an electronic system's life to make sure the equipment will be electromagnetically compatible with other systems. It is much easier to implement fixes during system design than to do so after they are already fielded.

Even with upfront engineering, unpredicted EMI problems are bound to occur. EMI problem solvers have a role in both EMC certification and "Big Bang" testing to reduce the risk of mission degrading EMI to the fleet. During a ship's EMC certification, various EMI recognition tests and system-to-system interoperability tests are performed to determine the current EMC posture of a deploying ship. During Big Bang, each electronic system aboard the ship is monitored by an EMC engineer while systems are turned on sequentially from highest frequency to lowest frequency. Most of the EMI problems solved to date have been discovered during an EMC certification or Big Bang.

**Figure 1.** Like USS *Dwight D. Eisenhower* (pictured here), most ships have limited real-estate for topside electronic equipment.

Certainly, not every maritime scenario and equipment configuration can be evaluated during the EMC certification or Big Bang. Initial indications of EMI—such as strobes on a radar display or an unusually high bit-error rate on a communication system—are investigated by ship personnel. When a problem cannot be easily resolved, the fleet contacts EMI problem solvers from SEMCIP to address and resolve the issue. SEMCIP has the surface Navy's top echelon of technical expertise in resolving EMI problems.

When SEMCIP is contacted to solve a shipboard EMI problem, a team of engineers will travel to the ship, sometimes in port and sometimes at sea, to perform testing and investigate the problem in detail (see Figure 2). Standard equipment includes a spectrum analyzer, oscilloscope, test antenna, directional couplers, current probes, and assorted cables and connectors. Spectrum characteristics, such as frequency and power level, must be ascertained in order to identify possible EMI source(s). Spectrums are observed at various places in the receive path of a system to determine where the problem actually occurs: sometimes at the output of a directional coupler of a transmitter, sometimes from an intermediate frequency test point, sometimes using a magnetic field clamp, and sometimes above deck using a directional test antenna. If EMI is continuous wave (CW), then that would indicate a communication system as the culprit; if EMI is pulsed, then that would indicate a radar system. Other key indicators to the EMI problem solver are the pulse repetition frequency, any potential pulse stretching, nonlinearities and intermodulation, or unusually high noise levels.

**Figure 2.** Two EMC Engineers Analyze Spectrum Characteristics to Solve an EMI Problem

The victim system can also provide valuable information in the search for the EMI source. System faults can indicate and isolate the problem to specific functions or locations in the system. Other system indications, such as number of uncorrected and corrected errors, could assist an EMI problem solver in determining the type of interference present, such as whether there are random or burst errors.

Turning potential systems on and off to see if the problem goes away is probably the most effective way to identify a problem; however, this is usually the last step, because turning off systems adversely impacts the ship operation. Usually, test windows must be coordinated with ship personnel so that critical systems can be turned off safely without impacting current operations. Radar and communication systems on board ships have specific functions that are required for specific ship operation. For example, when aircraft are landing on a carrier, any equipment relating to avionics must be fully operational. Proper coordination is essential for EMI problem investigation on ships.

## Analysis and Resolution

Once an EMI source is identified, key information that characterizes the problem can be used to determine a suitable fix. Extensive analysis must be done to pinpoint the exact cause of the EMI problem. Some of the questions that need to be answered are:

- What frequencies are causing the interference?
- Under what weather conditions does the EMI occur?
- Does EMI only occur at certain times or at certain pointing angles of the victim antenna?
- Does the interference happen only at night or in certain geographical locations?
- How degrading is the interference?
- What impact does the EMI have on the operational capability of the ship?
- Is the interference on board or from a nearby ship?

These and many other questions must be addressed to determine the best method to mitigate the problem. Problem solvers also assess whether the problem should be corrected at the EMI source equipment or at the EMI victim.

Problem mitigation has varying degrees of complexity. Sometimes there is a simple course of action that can alleviate the problem, such as using another radar waveform, changing coding rates, using more or less signal power, or changing some other setting on the source or victim system. Moreover, sometimes the source system has a faulty component or is operating out of its intended or assigned frequency range. A simple replacement of a component could fix the problem.

Other examples of fixes commonly used to correct EMI problems are metallic tape, radar-absorbing material (RAM), filters, and frequency management. Metallic tape wrapped around components or cables provides additional shielding and creates a solid ground to prevent case-cable penetration (see Figure 3). Although metallic tape is relatively inexpensive and easy to install, it is preferably used as a temporary fix until a more permanent solution is designed and implemented. It is the "duct tape" of the EMI world.

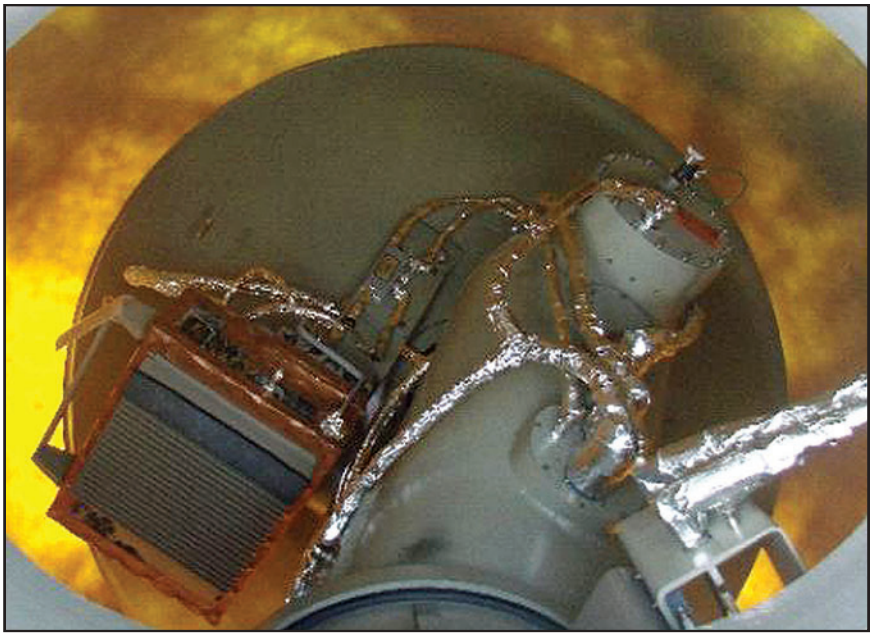

**Figure 3.** Initial Attempts to Shield Components in the Radome of a Communications System

RAM is also a useful tool for EMI control. RAM is often attached to barriers placed between the EMI source and victim to increase isolation and reduce the coupling of electromagnetic energy. RAM is also used on superstructures to prevent reflections. Shipboard signals often reflect off solid metallic structures, such as the ship's mast and superstructure. These reflections can couple into other radar and communication antennas or penetrate through cables and other components.

Perhaps the most commonly used form of EMI mitigation is a type of filter (see Figure 4).

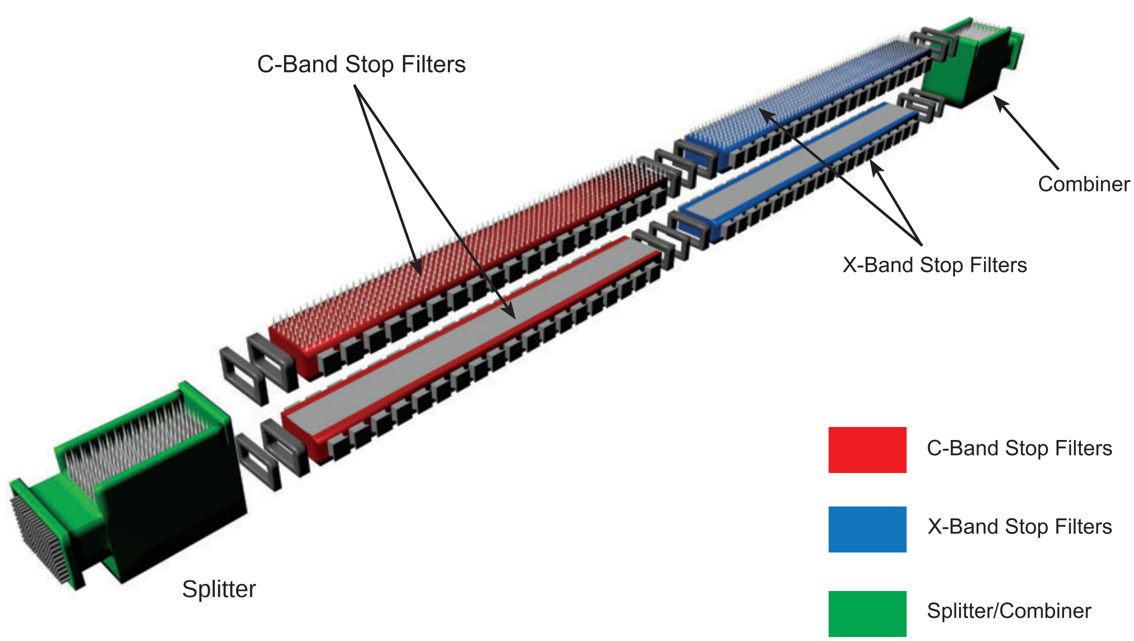


**Figure 4.** Diagram of the AN/SPS-48 Transmit Waveguide Filter

EMI filters can be used on power lines, in the transmit path, or in the receive path. EMI problem solvers assess whether the best implementation is band-pass, band-reject, or another alternative. Off-the-shelf filters are preferred due to low cost and availability. Many times a new filter must be designed to fulfill the frequency, attenuation, and insertion loss requirements. Prototype filter delivery can take many months, causing substantial delays in implementation and testing. The EMI problem solver must evaluate the trade-offs in system performance when selecting filters and other microwave components.

Frequency management is a very useful method to fix EMI problems. By avoiding certain frequencies or channels, an EMI source can prevent EMI to a victim system. Similarly, a victim can be restricted to certain frequencies or channels to avoid being interfered with. Frequency management is sometimes not the preferred solution because it can limit a system's capability to function as intended.

## Necessary Working Relationships

EMI problem solvers must interface with many organizations both internal and external to the U.S. Navy. Government program managers provide leadership and life-cycle support for various programs in the Navy. Industry develops and builds the hardware and software required for the warfighter to achieve military objectives. Filter and microwave component manufacturers provide important tools necessary to mitigate EMI. Various ISEAs provide logistical and engineering support to the fleet on a specific system. Sailors and fleet commanders report EMI problems, report operational limitations resulting from EMI problems, and help coordinate ship visits to resolve the problems. EMI problem solvers must be capable of working with all these organizations and maintain a good working relationship with them in order to effectively identify problems and implement solutions. The most effective method to solve challenging EMI problems is to have a team of subject-matter experts, including EMC engineers and problems solvers (see Figure 5), systems engineers from the U.S. Navy's ISEAs, and sailors who operate and maintain systems on a daily basis. These relationships are critical to both the upfront engineering EMC analysis, as well as the urgent problem solving for deployed forces.

## Conclusions

There is no standardized procedure available to identify EMI problems, because there are no standard EMI problems. Each problem is unique with different characteristics and level of complexity. That is why electrical engineers are required to identify, investigate, and characterize EMI and then provide practical EMI fixes. It takes an engineering mindset to analyze and determine the best way to solve and fix problems. Additionally, there is no standard method of EMI problem solving that a handbook could address. The EMI/EMC area is continually affected by new challenges due to the variety and evolving complexity of electronic systems being installed on ships.

Many electrical engineers developing military systems are unaware of the challenges present in the electromagnetic environment and do not recognize the importance of EMC. It is up to EMI problem solvers to ensure that new systems installed on ships are successfully integrated with existing electronic equipment. Many challenges lie ahead for the U.S. Navy's EMI problem solvers, but many of these engineers are eager for the challenge and are willing to do whatever it takes to assist the warfighter in defending our country and the freedoms we enjoy.

**Figure 5.** EMI Problem Solvers Troubleshoot a Navigation Radar

# The AN/SPS-67 Waveguide Filter

*By Rick Gustavus*


## The Spurious Noise Problem

The AN/SPS-67 radar is used as navigation radar on many Navy ships, This particular antenna configuration radiates or transmits frequencies that are generated within the AN/SPS-67 radar systems magnetron. Some of the frequencies generated are outside of the fundamental or main frequency of the AN/SPS-67 radar system, but they are also transmitted and are known as spurious noise. Spurious noise can get into one of the nearby satellite communications (SATCOM) systems and cause it to lose lock on a satellite that is in orbit over the Earth. This loss of lock on the satellite could be likened to when you are listening to your car radio, and just about the time you hear the most important part of what you're listening to, everything goes to static. Likewise, there are certain sections of the frequency band of the SATCOM system where this spurious noise may occur at a critical moment of a conflict. When it does, the SATCOM communications link would be lost, which could impact mission success. A depiction of the AN/SPS-67 radar system is shown in Figure 1.

## The Pursuit of a Spurious Noise Solution

To deal with spurious noise, a temporary filter was initially developed that employed a sulfur hexafluoride (SF6) gas as an insulator gas to prevent arcing within the filter that could occur due to the AN/SPS-67 radar system's high-power interacting (arcing) within the internal design features of the filter. The storage of the gas cylinders, the leakage of the gas, and many other idiosyncrasies made the design less than optimal; however, it was the only available technology at the time to correct this problem. An SF6 filter is shown in Figure 2.

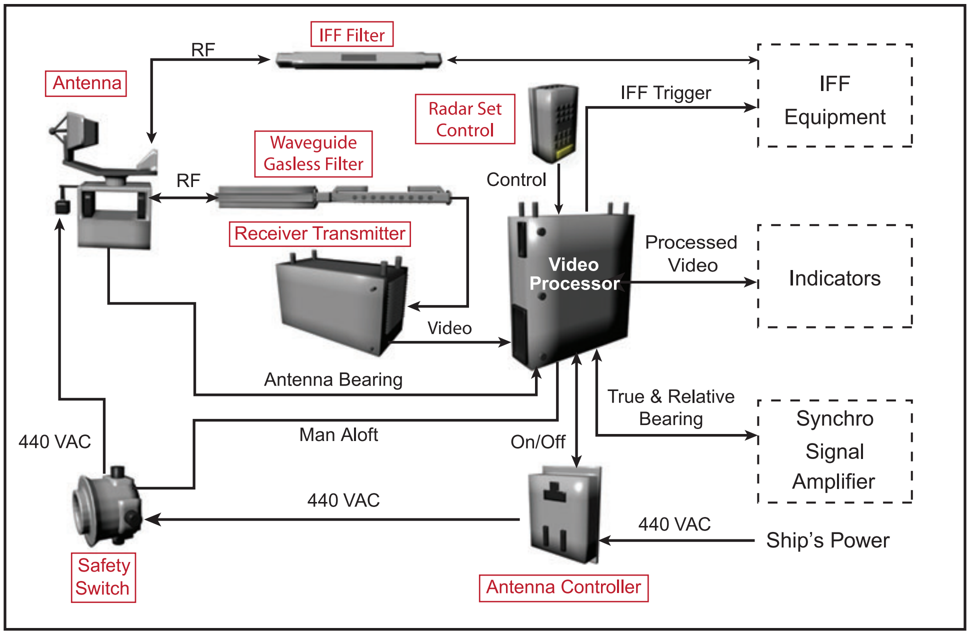


**Figure 1.** The AN/SPS-67 Radar System

band), while the absorptive section of the filter then took over and provided all of the rejection at the upper skirt.

In looking more closely at the 3-dB hybrid section of the filter, we gained the advantage of eliminating any insulating gas, as this portion of the filter splits or divides the power coming from the AN/SPS-67 radar (magnetron) and then recombines it again at the output of this filter section. The absorptive section of the filter had a unique characteristic that literally "absorbed" all spurious noise frequencies remaining above the fundamental frequency and, in doing so, would not allow those spurious noise frequencies to pass up to the AN/SPS-67 radar antenna.

Without the filter, the spurious noise would be passed up to the antenna, amplified by the gain of the antenna, and then transmitted into the surrounding atmosphere, where interference with the SATCOM system could cause mission degradation and loss of mission capability. Because the filter is bidirectional, it can be installed in either direction. But for the purpose of the illustration shown in Figure 3, the power is first shown entering the 3-dB hybrid section of the filter. The power is then split or divided and then recombined as it leaves this filter section that allows the elimination of any insulating gas because, simply speaking, the power has been cut in half. The connection from the magnetron to the antenna of the AN/SPS-67 radar system through which the transmitter signal power travels up to the antenna is called ***waveguide***, and it looks like rectangular tubing. This rectangular tubing is specifically sized for the frequency of the AN/SPS-67 radar system. The various spurious noise frequencies that originate from the AN/SPS-67 magnetron travel along

Gas usage and storage, as well as the added maintenance costs associated with using SF6 were among many leading concerns preventing any immediate fleetwide installation of this filter. Consequently, a continued search for a filter design with a mature technology that did not require any insulating gas was found in work coming out of the Doppler weather radar field. This filter consisted of two types of filters (a 3-dB hybrid section and an absorptive section) that were combined to perform the function required to satisfy the pass-band requirements needed to eliminate the spurious noise of the AN/SPS-67 radar system. The overall filter basically created a sandbox for the AN/SPS-67 radar system to play in without impacting any other system around it. The filter used a 3-dB hybrid passband filter that provided rejection at the lower skirt (or lower range of the AN/SPS-67 radars frequency band, and part of the rejection at the upper skirt, or upper range of the AN/SPS-67 radars frequency

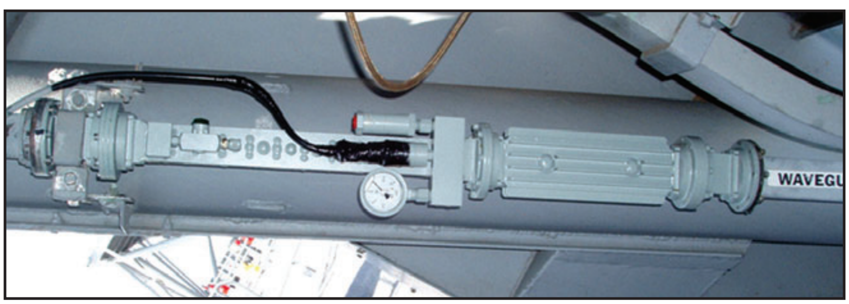


**Figure 2.** Sulfur Hexafluoride (SF6) Gas-Filled Filter Installed Aboard USS *Tarawa*

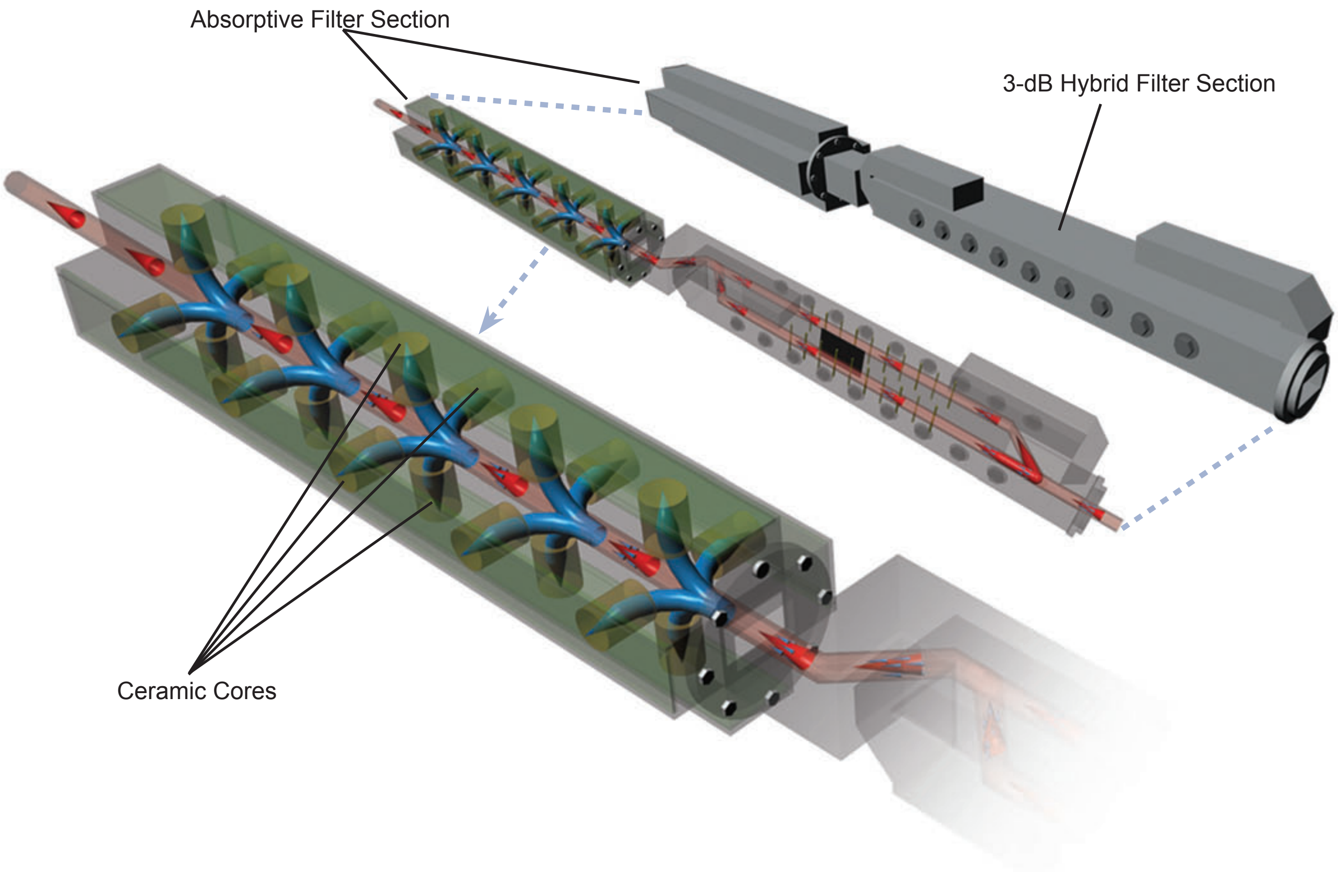


**Figure 3.** AN/SPS-67 Waveguide Gasless Filter

either the wide wall or the short wall of the waveguide and as indicated by the arrows in Figure 3. The effect of any frequency (indicated in blue)—other than the fundamental frequency (indicated in red)—is absorbed into the respective ceramic rods. These ceramic rods are doped to a certain capacitive characteristic, are sized to a specific diameter, and are then built into the walls of the absorptive filter. One must consider that any impact to the design of the filter must be done without affecting the performance of the AN/SPS-67 radar system. One of the biggest challenges was testing the filter for the ability to meet this very important performance capability for all the infinite possible frequencies.

## Testing of the Filter

Testing of the filter was accomplished with the submission of two filters in four phases of testing: harmonic frequency rejection testing; laboratory testing; land-based testing; and power testing. Harmonic frequency rejection testing was one of the critical performance characteristics of the waveguide filter. The filter's ability to deal with all of the harmonics/frequencies above the TE101 mode generated by the AN/SPS-67 radar systems magnetron and then transmitted by the (V)1 antenna was critical. The elimination of these harmonics/frequencies was of primary concern because of the impact to the AN/WSC-6 SATCOM system and other collocated systems. Harmonic/frequency testing could be accomplished only by subjecting the filter to an environment of infinite frequencies and then measuring the resultant spectrum at the output of the filter.

Testing involved creating two chambers, one on each side of the filter, and injecting all frequencies below and above the frequency range of the filter into one of the chambers. The frequencies or output were measured in the other chamber and determined the dynamic performance properties of the filter. The testing concluded that the waveguide filter successfully rejected all harmonics/frequencies above the TE101 mode in the frequency range of 7 to 12.8 GHz.

Laboratory testing was conducted in the NSWC Dahlgren, E3 Force Level Interoperability Laboratory and was done to evaluate the filter's frequency response and insertion loss performance. This testing would more closely determine

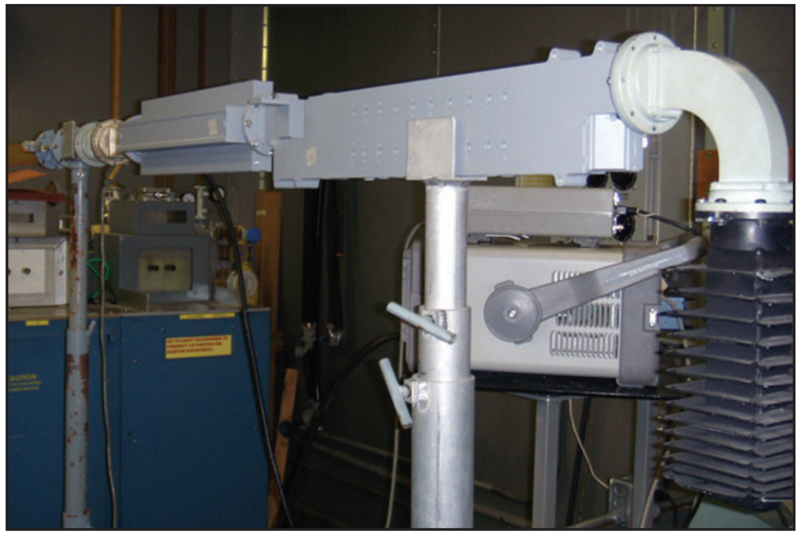

**Figure 4.** Waveguide Filter Connected to 1 Megawatt Magstand for Power Test

the frequency range at which the waveguide filters began to pass certain frequencies, as well as specifically define the cut-off frequencies of the filters. A critical change had been made to the pass-band frequency specification. Therefore, it was necessary to make a determination of compatibility with the AN/SPS-67 radar system pulse widths and ensure that there would not be cause for concern of a decrease in power output to the radar system by the filter. Subsequent testing with the band-pass filters installed in an AN/SPS-67 radar system at Dam Neck, Virginia, using targets of opportunity, confirmed that the filters did not degrade target detection.

Land-based test events employed an actual operating AN/SPS-67 radar system to verify the effectiveness and performance of the filter design. The AN/SPS-67 radar system was operated, and the radiated spectrums were measured in order to gauge spurious noise suppression and to ensure compatibility with the AN/SPS-67 radar system. The resultant data showed that the gasless electromagnetic interference (EMI) filters developed for the spurious noise suppression of the AN/SPS-67 radar system were, if fact, compatible with the AN/SPS-67 radar system and did not degrade the performance of the AN/SPS-67 radar system. The waveguide filter was then subjected to an unpressurized environment and a maximum peak power equivalent to that of the AN/SPS-67 radar systems of 285 kW peak power (214 W average power). At 285 kW peak power, a transmitter ON/Off test was conducted to confirm that no arcing would occur when this maximum power was introduced and interrupted in the unpressurized environment. The power was then increased up to the maximum of 570 kW to verify the 300% safety factor requirement. A photograph of a waveguide filter power test is shown in Figure 4; Figure 5 shows me holding the filter.

Clearly, the spurious noise issue was a problem for the AN/SPS-67 radar, and it presented significant challenges as a solution was steadfastly pursued. Fortunately, through hard work and determination, a solution was found and, as a result, this navigation radar will operate more effectively and accurately, enhancing the Navy's navigation capabilities today and in the future.

**Figure 5.** Author with AN/SPS-67 Waveguide Filter

# New Broadband Satellite Terminals Installed on Smaller Ships

By Wayne Gaston

The Naval Surface Warfare Center, Dahlgren Division's (NSWCDD) Electromagnetic Effects Division supported the recently completed installation of a "first in class" Commercial Broadband Satellite Program (CBSP) antenna system on board the Little Creek-based Patrol Coastal (PC) ship USS *Hurricane* (PC 3) (see Figure 1). The installation, which was completed with close coordination with the Program Executive Office, Command, Control, Communications, Computers, and Intelligence Office (PEO C4I); the Space and Naval Warfare Systems Command (SPAWAR); and the Patrol Coastal Squadron (PCRON) provides the ship—and eventually the entire class—with at-sea, broadband connectivity for the first time.

The CBSP replaces the older satellite system, INMARSAT, which is no longer capable of providing the necessary bandwidth to support the Navy's requirements for tactical operations or the shipboard environment for today's modern sailor. It is part of a SPAWAR program to deploy a new generation of shipboard satellite terminals that will enhance the bandwidth for ships as much as 10 times faster than previous versions, up to 3.8 megabits per second (Mbps) in a constant "on" connection. The systems are also much smaller and can be installed on almost any naval platform without taking valuable real estate from other warfare systems. The newer satellite system enhances interoperability for all warfighters, whether assigned to aircraft carriers, amphibious assault ships, cruisers, guided-missile destroyers, or even 180-foot PC ships. Sailors have a win-win situation no matter where they are stationed. They will be able to transmit voice, video, and data much faster to stay connected in our global 24/7 environment.

For USS *Hurricane* and the rest of the Navy's PC ships, there's more than just the antenna system. CBSP will support an entire new:

- Program of Record (POR) network system that includes Secret Internet Protocol Router Network (SIPRNET)
- Non-Secure Internet Protocol Router Network (NIPRNET)
- Integrated Shipboard Network System (ISNS) servers and switches
- Combined Enterprise Regional Information Exchange System (CENTRIX) servers
- Automated Digital Network System (ADNS) components

The new local area network (LAN) is also tied into the ships' private branch exchange (PBX) switches for secure telephone operations.

With crews of about 25 sailors, PC ships will now be outfitted with 22 total personal computer/

**Figure 1.** USS *Hurricane* (PC 3) returns 23 October 2008 to homeport, Little Creek Amphibious Base Norfolk, having completed sea trials and System Operation and Verification Testing (SOVT) for its newly installed CBSP Small Ship Variant (SSV) communications terminal.

printer drops, of which 13 will be for unclassified systems, 7 will be for classified information, and 2 will be CENTRIX terminals. They will be used by 17 Dell D630 laptops and 5 HP4250 printers. The ship's ADNS will provide ship and shore internet protocol connectivity, automating the routing and switching of tactical and strategic C4I data among and between deployed battle groups and the Defense Information Systems Network. One component of the CENTRIXs will allow the ship to have "same time chat," which is the primary method of sharing real-time information among ship and shore commands. The next two PCs to get this new configuration of CBSP and PC NETWORK are USS *Chinook* (PC 9) and USS *Sirocco* (PC 6), both homeported in Bahrain. If all goes as planned, all PC-class ships should have their new systems installed by the end of 2009.

To facilitate the design and system characteristics to help meet installation and operational criteria, NSWCDD has been an integral part of an integrated planning team with the system's program managers (PMW 170) from the beginning of this initiative. Using historical electromagnetic compatibility (EMC) data, along with shipboard and on-site testing and analysis, a Dahlgren team of EMC engineers continues to work with the CBSP program managers to ensure that the Navy receives the best possible satellite terminals. They also provide the technical leadership to mitigate electromagnetic interference (EMI) with any and all systems being installed, whether they are below-deck wireless systems or topside warfare and communications configurations. From results of the initial EMC certification testing on board USS *Hurricane*, the CBSP system indicates that the hard work and integrated planning by all parties will pay great dividends to all, especially the fleet sailor.

USS *Hurricane*'s Commanding Officer, Lieutenant Commander John Barsano (see Figure 2), and Communications Specialist IT1 Evan Weber, provided direct support with all phases of installation of the upgrades. They coordinated the testing events needed for CBSP systems operations and the verification tests by SPAWAR, and both the EMI characterization testing and the EMC certification by NSWCDD. Without the direct involvement of both Barsano and Weber, under strict time constraints, completion deadlines might have been missed, placing both installation and testing phases in jeopardy. By meeting all deadlines, it was then possible to meet follow-on NSWCDD and SPAWAR deadlines to ensure that the next SSV installed on

USS *Chinook* would have the EMI upgrades needed as a result of all previous testing. USS *Chinook's* install remains on track for early 2009 completion, with the remaining PCs and mine countermeasures (MCM) ships to follow.

Even though there are many unknowns regarding the new system and how it will perform in its intended operating environment, both Barsano and Weber believe the new system will greatly enhance the overall warfighting readiness of the entire Navy. Being the first PC ship to have this capability provides the ship's crew the opportunity to acquire the most experience and skills in troubleshooting any issues that might arise. They will also provide invaluable feedback on the system. This is very important, especially with regard to EMI issues, to ensure the best EMC posture that a fleet can have during a wartime environment. Weber also believes that the ability to use "CHAT" on SIPR and CENTRIX with U.S. and Allied commanders is a major enhancement to the role the PCs play in the Persian Gulf. While this new technology has many pros for both sailors and fleet commanders, there will likely be "unknowns" regarding the limitations and risk associated with the system. Referring to the various environments the new system will be subjected to, both SPAWAR and NSWCDD will be relying on sailors to also provide feedback on operational and interoperability issues that can be used for continued system improvements. With the continued cooperation of USS *Hurricane*'s crew (as well as subsequent ships), the CBSP Program should continue to improve the scope of naval communications and allow sailors to get up-to-date information and be part of the "constant on" generation.


**Figure 2.** On 4 December 2008, IT1 Evan Weber (left) and Commanding Officer, Lieutenant Commander John Barsano (right), stand on the deck of USS *Hurricane* (PC 3) with the new CBSP satellite terminal.