Radionavigation Bulletin

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Local Corrections, Disparate Uses Cooperation Spawns Nationwide Differential Global Positioning System

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The maritime differential GPS (DGPS) network operated by the U.S. Coast Guard (USCG) provides position accuracy and signal integrity needed to meet Coast Guard navigational requirements on inland rivers, harbors, and harbor approach areas up to a minimum of 20 nautical miles off-shore of the continental United States, Puerto Rico, and selected portions of Alaska and Hawaii.

The network, which achieved Full Operational Capability (FOC) in March 1999, is a land-based augmentation system. It receives and processes signals from GPS satellites, calculates corrections from known positions, and broadcasts these corrections via a medium frequency (MF) transmitter to DGPS users in the broadcast site's coverage area. DGPS corrections bring accuracy to within 1 meter at the base of the tower, the signal experiences about 1 meter of further degradation for every 150 kilometers of distance from the broadcast site.

The Coast Guard's parent agency, the U. S. Department of Transportation (DOT), in collaboration with several federal and state agencies, is now expanding DGPS to cover the country's interior by coordinating the implementation of a Nationwide Differential GPS (NDGPS) network.

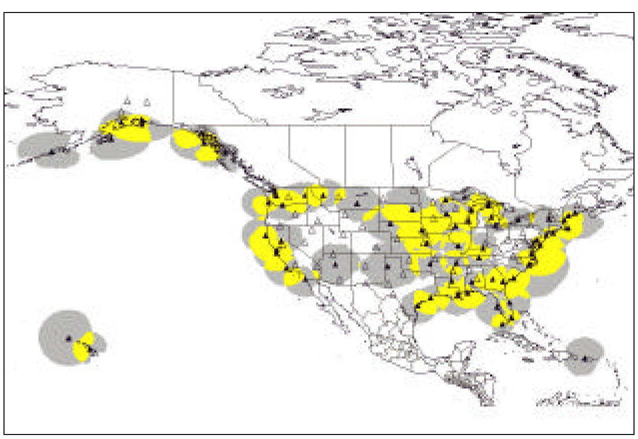

Figure 1: DGPS/NDGPS coverage, as of November 2001

After reviewing several options, DOT determined that the most efficient and cost effective method of providing this expanded coverage would be to convert 47 obsolete low-frequency (LF) U.S. Air Force Ground Wave Emergency Network (GWEN) sites into NDGPS broadcast sites, based upon USCG standard DGPS site design. Reusing a GWEN site saves over $750,000 in construction and equipment costs when compared to constructing a new site. NDGPS utilizes essentially the same equipment configuration as the Coast Guard's DGPS — namely, two reference stations to calculate differential corrections, two integrity monitors to verify correction accuracy, and a transmitter to amplify the reference station correction data through an MF antenna. The unmanned broadcast sites are remotely monitored continuously by one of two DGPS control station over a wide area network (WAN). In case either control station should fail, the other one can control all of the broadcast sites. In addition, the support baseline system at the USCG Command and Control Engineering Center (C2CEN) can double as an operational control station, providing another back-up option. When completed, this network will consist of 126 sites and will provide redundant standard DGPS C/A code corrections for a variety of users nationwide.

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From the Commanding Officer...

<u>The changing face of radionavigation</u>

Ever wonder what forces have come together that culminates in the dial tone making its way to your telephone receiver? A lot is going on in the background that most people don't know nor care to know, but when most people lift that phone, their expectation for that tone to be there is akin to the sun coming up in the morning.

As we have come to depend on the dial tone, we are growing the same relationship with navigation signals. Nowadays, almost every aspect of your life is touched if not dependent on GPS, DGPS and Loran C for position and timing services. What we need to consider is how that dependence impacts our safety and efficiency should the signal not be of the quality or availability we need. At the highest levels of government, this key question is being asked among modal leaders in an effort to define what requirements need to be expressed, planned and implemented. What this leads us to also is a new set of definitions that I'd like to describe here.

In most fora that addresses the issue of GPS back up, the players discuss the details without adequate context. Recently, I ran across an expression of context that makes the most sense to me. Here it is…:

<u>Redundancy</u> – a separate system that, when the primary system is unavailable, provides the same level of service so that the user can continue without disruption.

<u>Back-up</u> – a separate system that, when the primary system is unavailable, provides a lesser but acceptable level of service so that the user can continue without disruption.

<u>Contingency</u> – a separate system that, when the primary system is unavailable, provides a lesser level of service that allows the users to get to safe haven.

Context is an important aspect because it becomes a critical factor towards expressing needs and requirements of the user community. These needs and requirements in turn must be translated into what systems we support and how these systems are operated. In some applications, an alternative system may not be necessary…in other words the user is not adversely impacted by an outage. Others, such as in aviation, require redundancy. Maritime requirements will be defined with regard to specific port, application (primary means of navigation or situational awareness) and conditions on-scene.

It may well come to pass that, in the coming age of eNavigation, each port will have procedures and instructions in place for entering or departing similar to approach plates for airports. This new age will reap new efficiencies but will require a new way of thinking about radionavigation and its role as the dial tone for commerce.

As I write this, my final column in the Radionavigation Bulletin, I am but a few weeks away from the Change of Command where I will be relieved by CAPT Curtis Dubay. First, let me say that I could think of no better choice for Commanding Officer of the Navigation Center. He is in my opinion, the premier radionavigation expert and is in touch with all the issues that we are dealing with across the spectrum of operations, system modernization, future improvements and user requirements. Lastly, it has been a privileged to work with all of you these three years and I hope that our paths cross again as I move to my new assignment as Chief, Office of Command and Control Architecture (G-OCC). *As Garrison Keillor says, "Be well, do good work and keep in touch".*

—– CAPT Tom Rice, NAVCEN

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NDGPS is now operational with single-station coverage over about 80 percent of the continental United States and is expected to be fully operational with dual-station coverage throughout the continental United States and Alaska two years after capital funding is received. NDGPS provides a GPS integrity monitoring capability; it gives an alarm to users within 5 seconds of detecting a fault with the signal from any GPS satellite. NDGPS signals are available to any user who acquires the proper receiver, and there is no user fee.

Applications. NDGPS will replace older systems, supplement current ones, and obviate the need to build new ones. It will

• replace the existing U.S. Army Corps of Engineers (USACOE) microwave positioning system and reduce or eliminate the agency's requirements to develop independent DGPS networks for vessel navigation and positioning;

• provide raw GPS observables to the National Geodetic Survey (NGS) for use in the continuously operating reference stations (CORS). This is a national network of more than 250 geodetic-grade GPS receivers whose data are made publicly available for post-processing applications in receiver independent exchange (RINEX) format, for use in land surveys, geographic information systems (GIS), and environmental management;

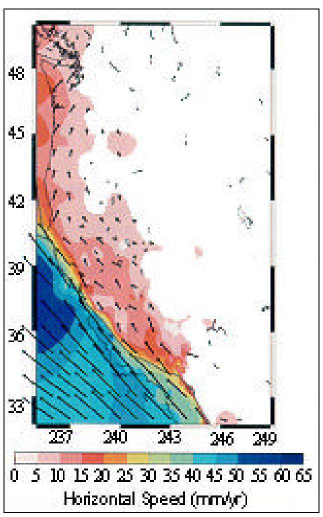

Figure 2 : Plate tectonic measurements (UNAVCO)

• allow the National Oceanic and Atmospheric Administration (NOAA) to collect meteorological and GPS data for analysis by installing equipment at DGPS sites;

• allow the University Navstar Consortium (UNAVCO) to collect data for use in monitoring the deformation of tectonic plate boundaries;

• provide data to measure the amount of precipitable water vapor in the atmosphere above the sites;

• aid real time or post-process positioning applications, such as 911 response, automatic vehicle location (AVL) for public transit and other fleets, land-use planning, and tracking of hazardous materials.

History

In January 1996, the maritime DGPS system entered the Initial Operational Capability (IOC) phase in which signals from 51 DGPS broadcast sites were available for positioning and navigation. To achieve IOC, USCG co-located six of its broadcast sites on property owned by three USACOE districts. USCG performed site design, installed equipment, and erected antennas at these locations and continues to provide primary maintenance.

Later that year, the President assigned responsibility for all civilian GPS matters to DOT and charged it with implementing a national GPS augmentation system for terrestrial transportation. In January 1997, DOT formed the DGPS Executive Steering Group (ESG) and Policy and Implementation Team (PIT) to carry out this mandate. After opting to convert GWEN sites into DGPS broadcast sites, as mentioned earlier, and establishing and testing a successful prototype GWEN - to - DGPS conversion site at Appleton, Washington, the ESG called for the expansion of the Coast Guard's DGPS network into a nationwide system.

Besides the Coast Guard, the partnership for development and implementation of the DOT's NDGPS initiative includes six other agencies: the U.S. Air Force Air Combat Command (ACC), the Federal Railroad Administration (FRA), the Federal Highway Administration (FHWA), NOAA, USACOE, and the Office of the Secretary of Transportation (OST). USCG has also established partnerships with USACOE districts serving the Mississippi, Missouri, Arkansas, and Ohio rivers to facilitate the construction of eleven DGPS broadcast sites.

In February 1997, as the maritime DGPS system entered the Full Operational Capability (FOC) phase, USCG had 54 active DGPS broadcast sites for positioning and navigation and monitored there signals for correction accuracy.

Subsequently, USCG equipped ten of these sites with equipment from the National Weather Service's Forecast Systems Laboratory's GPS Surface Observing System (GSOS), to receive meteorological data as part of the Integrated Water Vapor demonstration project. This system measures water vapor content of the column of atmosphere above the broadcast site, significantly enhancing weather forecast models.

In 1999 and 2000, ACC transferred 54 GWEN sites and all GWEN spare parts to the Coast Guard. This significantly reduced NDGPS start-up costs while saving on USAF decommissioning costs.

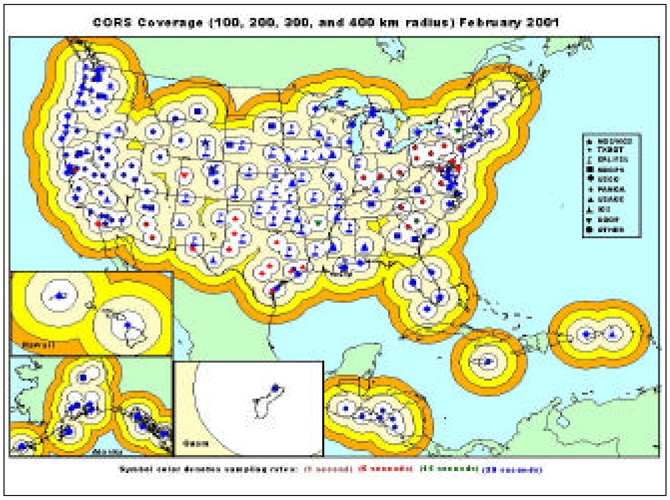

Figure 3: CORS coverage with 100-, 200-, 300-, and 400-kilometer radius, as of February 2001. Symbol color denotes sampling rates: brown, 1 second; red, 6 seconds; green, 15 seconds; and blue 30 seconds

Sharing Resources

All of these partnerships between federal agencies to share equipment and/or resources date back to the inception of the maritime DGPS network, in 1995. Each partnership is formally documented with a Memorandum of Understanding (MOU) that details responsibilities for each party. (see "Partnerships" p. 7)

As the maritime DGPS system expanded to nationwide coverage, new partnerships developed to provide network design (FHWA), environmental permitting (FHWA), antenna siting/GPS signal analysis (NGS), and developing the requirements and securing the funding for NDGPS (FRA).

These federal agencies also established partnerships with state and local agencies to acquire property and build new NDGPS broadcast sites.

Budget Process. To date, the NDGPS program has spent approximately $19 million in construction, engineering, and support. Each year, the FRA requests an NDGPS budget. Upon approval of funding by the Executive Branch, the NDGPS PIT then selects and prioritizes the number of sites to be converted or installed and the location for new NDGPS service, usually a specific town or city.

Network Design

Following the GWEN-to-DGPS conversion at Appleton, Washington, mentioned earlier, a preliminary NDGPS network design was completed by the National Telecommunications and Information Administration (NTIA). This analysis modeled various parameters — including numbers and locations of broadcast sites, effective radiated power, and transmit frequencies — and provided the basis for a network design for overlapping signal coverage across the continental United States.

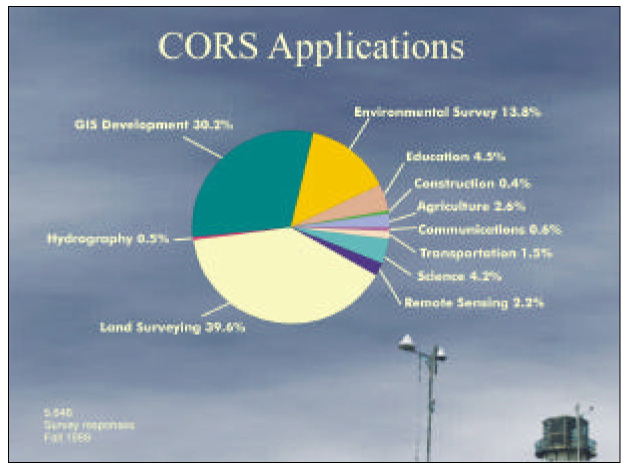

Figure 4: CORS applications

Antennas. GWEN was a highly redundant network of low frequency broadcast sites hardened to withstand electromagnetic pulse in case of nuclear attack. The reused transmit antenna at a converted GWEN site is 299 feet tall and has twelve Top Loading Elements (TLEs). This configuration yields an efficiency of approximately 55 percent when operated in the medium frequency band (285 kHz to 325 kHz) used in USCG DGPS signal propagation, compared to 15 percent efficiency for other USCG DGPS antennas. The superior NDGPS antenna efficiency translates into an expanded coverage area at the same transmit power, reducing the number of required broadcast sites to meet DGPS signal requirements in a specified area.

Additionally, the USCG has modified the GWEN 5000-watt, low-frequency pulsed transmitter to also operate at USCG DGPS frequencies.

The USCG converted the transmitter to continuous wave operation and reconfigured the RF drive and power amplifier (PA) circuits for a maximum output power of 2500 watts. This allowed Coast Guard engineers to designate two of the four existing PA circuit card assemblies as installed spares.

To support the modified GWEN transmitters, the Air Force transferred to the USCG all the ready-for-issue and not ready-for-issue circuit boards it had in store. The USCG overhauled and tested these assemblies and placed them in its inventory stock to meet anticipated NDGPS supply requisitions.

New Site Selection

In the event a GWEN site is not available to provide the desired coverage area, the PIT establishes a new site. FHWA personnel begin this process by sending a standard site selection guide to a local state or federal agency representative, who then identifies potential sites within a 30– to 50– mile radius that meet the outlined criteria. The guide includes specifications for property size (11.2 acres), environmental concerns, availability of power and telephone service, and the impact of any nearby objects that could mask the GPS antennas or cause multipath interference. Upon completion of this stage of the site selection process, collaborating agencies have narrowed the number of potential sites down to two or three. The results are forwarded to C2CEN, which sends an engineering representative to visit these sites for a final survey before choosing one.

Future Initiatives. As new NDGPS sites come on line, the Coast Guard is evaluating co-locating them with its Long Range Navigation (LORAN) transmitting sites. As with the use of pre-existing GWEN sites, this co-location project will provide significant savings in land acquisition and construction costs, and consolidate maintenance costs for two radionavigation programs. Due to LORAN's critical timing and pulse shaping requirements, the engineering approach currently under evaluation is to use an existing top-load element (TLE) guy wire from the LORAN tower as an inverted **L** long wire antenna for DGPS signal propagation.

Conclusion

Federal and state agencies have demonstrated their ability to cooperate to build a multi-purpose DGPS that meets a varied set of user requirements. They achieved this through partnerships that respect each organization's mission, customer base, and skill sets.

Abbreviations

ACC	Air Force Air Combat Command
AVL	automatic vehicle location
C2CEN	USCG Command and Control Engineering Center
CORS	continuously operating reference stations
DGPS	differential GPS
DOT	U.S. Department of Transportation
ESG	Executive Steering Group
FHWA	Federal Highway Administration
FOC	Full Operational Capability
FRA	Federal Railroad Administration
GIS	geographic information systems
GSOS	National Weather Service's GPS Surface Observing System
GWEN	Ground Wave Emergency Network
IOC	Initial Operational Capability
LORAN	Long Range Navigation
MF	medium frequency
MOU	Memorandum of Understanding
NDBC	National Data Buoy Center
NDGPS	Nationwide Differential GPS
NGS	National Geodetic Survey
NOAA	National Oceanic and Atmospheric Administration
NTIA	National Telecommunications and Information Administration
OST	Office of the Secretary of Transportation
PIT	Policy and Implementation Team
RINEX	receiver independent exchange
TLEs	Top Loading Elements
UNAVCO	University Navstar Consortium
USACOE	U.S. Army Corps of Engineers
USCG	U.S. Coast Guard
WAN	wide area network

Partnerships

Each participating agency plays a specific role in the NDGP project.

• **OST —** Chairs the PIT

• **ACC —** Transfers GWEN assets to USCG for NDGPS use

• **USACOE —** Provides property management services and engineering design, construction, and environmental assessment services. In turn, implementation and use of DGPS will replace an existing USACOE microwave positioning system and will reduce or eliminate USACOE requirements to develop independent ultra-high frequency or very high frequency (UHF/VHF) DGPS networks for vessel navigation and positioning.

• **FRA —** Submits budget requests to Congress and advocates for them. Identifies and documents operational requirements and verifies performance requirements for railroad users.

• **FHWA —** Serves as the lead agency for environmental impact analyses and other environmental requirements. Identifies the number and general location of broadcast sites and their operating frequency. Performs coverage measurement analysis of each operational site. Coordinates with state and local governments to identify locations for new facilities.

• **USCG —** Manages real property; designs, installs, supports, and operates broadcast sites; and provides engineering expertise and support.

• **Tennessee Valley Authority (TVA) —** Provides civil engineering design and construction services. Refurbishes and stores USAF GWEN equipment and generator shelters.

• **NGS —** Provides geodetic coordinates for DGPS service, including monumentation, and assists USCG in the establishment, operation and evaluation of DGPS. In November 1997, NOAA and USCG agreed on the installation of surface meteorological sensors at ten DGPS broadcast sites for use in weather forecasting and climate monitoring. Specifically, NOAA will install GPS Surface Observing System (GSOS) equipment at ten DGPS sites and collect meteorological and GPS data for analysis. USCG will provide a location to install the equipment and primary power and data connectivity and will perform preventative and corrective maintenance. NOAA will install GSOS equipment at all NDGPS locations and at the remaining 44 maritime DGPS broadcast sites.

• **CORS Network —** CORS is a national network of over 250 sites containing geodetic-grade GPS receivers whose data are made publicly available for post processing applications. About one-third of these sites are DGPS and NDGPS reference stations. CORS code range and carrier phase data is used in post processing applications to calculate GPS-derived positions with accuracies that approach a few centimeters in three dimensions.

• **UNAVCO —** is an international organization of more than 90 universities and research instititions performing geoscience projects utilizing GPS technology. It began a partnership with DGPS in November 2000 as part of the Plate Boundary Observation Project. This involves adding high-precision geodetic-quality antenna monuments and survey-quality choke ring antennas to the standard NDGPS reference station design to facilitate sub-centimeter positioning for tectonic plate monitoring over long baselines. The first UNAVCO-style pedestal and antennas were installed at the NDGPS site in Myton, Utah in February of this year.

Other Applications

• **CORS—**Typical applications include land surveying, geographic information systems, and environmental surveys. Dedicated GPS reference station ports at each DGPS site provide raw GPS observables to a central NGS facility via the Coast Guard’s LAN. These observables are then converted and organized into RINEX files for public distribution through the Internet (<http://www.ngs.noaa.gov/CORS/> or <ftp://www.ngs.noaa.gov/cors/>).

• **Plate Boundary Observation Project —** The simplest view of plate tectonics implies that all deformation occurs across the boundary between idealized rigid plates. GPS data can show how this deformation varies in space and time and thereby help predict earthquakes.

• **GSOS —** Water vapor is the source of clouds and precipitation and an ingredient in most major weather events. GPS-IPW vapor monitoring is a ground-based technique that measures the integrated (total column) of precipitable water vapor directly above a fixed site. This method uses DGPS reference stations and surface metérorological sensors to measure excess GPS signal delays caused by water vapor in the atmosphere. The first GSOS test system was installed at the National Weather Service in December 1997. Fifty-six additional GSOS systems have been installed and GSOS equipment will be added to the remaining 44 maritime DGPS sites. GSOS payloads are included in new NDGPS site installations. Thirteen sites have been completed to date. When NDGPS reached full maturity and GSOS installations are completed as planned, the GSOS capable GPS-IPW network will increase to 180 locations.

Positive Train Control

NDGPS receivers placed on locomotives will calculate their location and speed. That information, transmitted back to a control center over the railroad's digital data network, will enable Positive Train Control (PTC). PTC systems integrate command, control, communications, and information systems for controlling train movements with safety, security, precision, and efficiency. PTC systems will greatly reduce the probability of collisions between trains, casualties to roadway workers, and overspeed accidents. PTC systems are comprised of continuous and accurate positioning systems such as NDGPS, digital data link communications networks, on-board computers with digitized maps on locomotives and maintenance-of-way-equipment, in-cab displays, throttle-brake interfaces on locomotives, wayside interface units at switches and wayside detectors, and control center computers and displays. PTC systems may also interface with traffic planners, work order reporting systems, and locomotive health reporting systems.

Remote Intervention. PTC systems track the location of the trains, issue movement authorities to trains and can automatically enforce them, and continually update operating data systems with information on the location of locomotives, cars, and crews. PTC systems will permit a control center to stop a train should the locomotive crew be incapacitated and will provide improved and more reliable running time, higher asset utilization, and greater track capacity. They will assist railroads managing costs and in improving energy efficiency. Pilot versions of PTC were successfully tested a decade ago, but the systems were never deployed on a wide scale. Deployment of PTC on railroads is expected to begin in earnest later this decade.

Data links. Digital data link networks can move information to and from trains, switches, control centers, yards, stations, maintenance facilities, data systems, and customers. They will replace many of today's voice communications and will effectively increase the capacity of communications circuits and frequencies. With data link communications, the information is digitally coded and messages are discretely addressed to individual or multiple recipients. The Federal Communications Commission has assigned to the railroad industry 182 frequencies in the VHF band and 6 pairs of frequencies in the UHF band. The UHF frequencies are being used for digital communications, and some railroads have converted some of their assigned VHF frequencies from analog to digital communications. The conversion is expected to accelerate during the coming decade. — Richard Shamberger

Further Reading

- "Implementing and Engineering an NDGPS Network," by David Wolfe, Connie Judy, Edward Haukkala, and David Godfrey, in *Institute of Navigation Proceedings, GPS-2000,* September 2000.

- "The National and Cooperative CORS Systems in 2000 and Beyond, " by Richard A. Snay, in *Proceedings of ION GPS-2000,* September 2000, pp.55-58; posted at <http://www.ngs.noaa.gov/CORS/information4/>.

- "2000 FSL/DD GPS-IPW Technical Review," by Department of Commerce, National Oceanic and Atomospheric Administration, and Forecast Systems Laboratory, posted at <http://www.gpsmet.noaa.gov/labreview/2000/GPS_Tech_Review_files/frame.htm>.

- "An Investigation of the Use of Differential Global Positioning System Technology within State and Local Transportation Departments," by Rudy Persuad, James A. Arnold, and Monther Hammoudeh, posted at <http://www.tfhrc.gov/library/states.htm>.

— LCDR Joe Chop, LCDR Amy Kritz,
David Wolfe, Connie Judy, C2CEN

Civil Global Positioning System Service Interface Committee Notes

The Civil GPS Service Interface Committee held its 39th Meeting in Springfield, Virginia from April 17 through the 19th of 2002. Approximately 160 GPS users and policy makers discussed the current activities, for three days. This meeting featured three discussion panels:

PO Stephen Park and PO Kishea Brown

1) *Information Distribution Issues*
2) *Interoperability of Regional Systems*
3) *The Future Radionavigation Mix*

In addition, the attendees were informed of developments in GPS Modernization, Systems Status, and the Augmentations.

The International Session included a description of the Japanese Regional Space-Based System (JRANS), the Indian SBAS system that will be a WAAS-type system, the benefits and difficulties of real-time differential corrections distributed by Internet, and the status of Galileo development. The Timing Session discussed the move no longer apply leap seconds, the project to do time transfer to a moving platform, and the security issues related to GPS-assisted vehicle routing.

Several U.S. States briefed the attendees on the recent developments and activities in their state. The update on the progress of High Accuracy Differential Global Position System (HADGPS) gave an encouraging outlook of what is obtainable with HADGPS.

The presentations are available on the NAVCEN website at: http://www.navcen.uscg.gov/cgsic/meetings/Default.htm#CGSIC Summary.

Information Dissemination Issues Panel

40th CGSIC Meeting

The next meeting of the CGSIC will be held in Portland, Oregon from September 22nd through the 24th of 2002, just prior to the ION Satellite Division Meeting. Current developments and issues in GPS will be discussed. For updates on the agenda and location, visit the NAVCEN website at www.navcen.uscg.gov/cgsic.

The Coast Guard Service Interface Committee is open to anyone with an interest in Global Positioning Systems.

— Rebecca Casswell, NAVCEN

Co-Locating DGPS and Loran Transmitters

Introduction

The United States Department of Transportation (DOT) is coordinating the implementation of a network of DGPS broadcast sites across the continental United States, Alaska, Hawaii and Puerto Rico. Several Federal and state agencies, including the Federal Railroad Administration (FRA), Federal Highway Administration (FHWA) and the United States Coast Guard (USCG) are involved in the effort to install the NDGPS Broadcast Network. When completed, this nationwide system will consist of over 126 sites and provide a standardized signal for DGPS service throughout the United States. Planned uses of the NDGPS network include positive train control, precision farming, smart vehicles, snow plow management, accurate waterway dredging, and improved emergency response - an expansion of traditional uses which include harbor/harbor approach navigation, vessel tracking and buoy positioning.[1]

The implementation of NDGPS is based on the existing network of USCG maintained maritime broadcast sites. The USCG's role in the project is to implement the expansion of new sites and provide maintenance and support for each transmitting facility. Although the NDGPS system uses identical reference station and integrity monitoring equipment as the maritime DGPS sites, the NDGPS sites have several differences. These include an alternate transmitter option, larger, more efficient broadcast towers, and a robust, highly reliable back-up power system. Most differences are the result of an agreement that transferred property from the U.S. Air Force (USAF) to the USCG.

At the same time the NDGPS project was gearing up, the USAF was in the process of decommissioning its system of Ground Wave Emergency Network (GWEN) sites. Although the GWEN sites were designed for a different purpose, the layout of each site and transmit antenna was well suited for DGPS broadcasts. The USAF transferred ownership of many of the GWEN sites as well as the assets that were staged to build additional GWEN sites to the USCG.

Although many of the existing GWEN sites were built in locations that provide much of the necessary coverage area for the NDGPS project, many holes exist that require construction of new towers. Locating property that meets the requirements for these sites has been challenging. Additionally, acquiring leases, the public notification process, and obtaining environmental clearances creates a large resource drain on the project. The entire process can stretch out to three years for some sites. The costs associated with building a new site are also about three times that of converting an existing facility. During a meeting of the USCG's DGPS RF NWG, an idea was suggested to combine the signals of a DGPS broadcast, and a LORAN-C broadcast onto a LORAN tower. This idea showed merit, especially after the previous successful diplexing effort of a DGPS and NAVTEX signal at the NDGPS site in Savannah, GA.

Diplexing DGPS with LORAN turned out to be much more challenging than diplexing with NAVTEX. The output power of a LORAN transmitter dwarfs the output of a DGPS transmitter. After looking at ways to minimize the destructive interference, the DGPS RF NWG decided to try a different approach. One idea was to feed the antenna from a different point than where the LORAN transmitter was connected. If a cable was connected to the end of a TLE and dropped straight down to connect to a DGPS transmitter, the resultant DGPS interference on the LORAN transmitter would be minimal and a filter would not be required on the output of the LORAN transmitter. Unfortunately, this approach was rejected by the USCG's tower community as unsound due to the downward force on the TLE. Another option would be to extend the length of the TLE down closer to the ground level. This method would alleviate any civil engineering concerns but would alter the LORAN tower and still present the problem of dealing with the large amount of LORAN RF at the DGPS transmitter. A third and best option is using a portion of the LORAN tower structure not used as a LORAN antenna. This concept eliminates almost all the destructive interference of the two systems while providing the benefit of sharing the tower structure. The concept was renamed from DGPS/LORAN diplexing to DGPS/LORAN co-location.

NAVTEX/DGPS at Savannah

In 1999, the USCG NDGPS Oversight Group was approached with the request to use the facilities at the proposed Savannah (Pembroke) Georgia NDGPS broadcast site for the purpose of also broadcasting a NAVTEX signal. This site was slated for conversion from a decommissioned USAF GWEN Repeater site to a state-of-the-art NDGPS site using the existing 290-foot antenna.

The standard GWEN style NDGPS broadcast tower is 299 feet with 12 TLEs and one hundred ground radials extending at a radius of 300 feet. **(Figure 1)** shows the layout of a typical site. Operating at 285-325 kHz, with a bandwidth of 30 to 80 kHz and a rate of 100-200 Bits Per Second (BPS), these antennas can radiate the DGPS MSK modulated signal at 55% efficiency. The Savannah NDGPS site operates at 319 kHz using a Southern Avionics SC-1000 Transmitter at a radiated output power of 60-1000 Watts (W). Traditionally, this transmitter would use a Southern Avionics PC1KILO Antenna Tuning unit to match the antenna to the transmitter. NAVTEX is an international automated MF direct-printing service for delivery of navigational and meteorological warnings and forecasts, as well as urgent marine safety information to ships within approximately 200 nautical miles of shore. The USCG operates NAVTEX stations in the U.S.[2]

The International Maritime Organization (IMO) has designated NAVTEX as the primary means for transmitting coastal urgent marine safety information to ships worldwide. NAVTEX broadcasts are made on 518 kHz using narrow-band, direct-printing, 7-unit forward error correcting transmission. The Amateur Radio community also uses the NAVTEX messages,

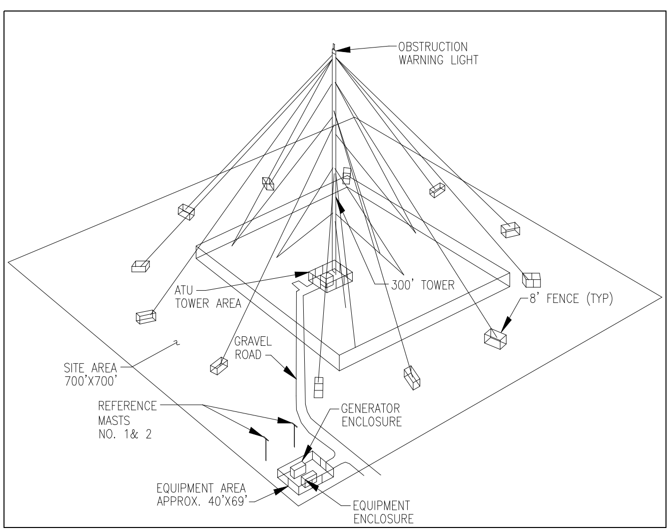

Figure 1 : Typical NDGPS Broadcast Site Layout

most often in the Amateur Teleprinting Over Radio (AMTOR) or Packet Teleprinting Over Radio (PACTOR) modes. These broadcasts use 100-baud FSK modulation with a frequency shift of 170 Hz. The center frequency of the audio spectrum applied to a single sideband transmitter is 1700 Hz. USCG NAVTEX transmissions are typically broadcast using a Nautel ND2500TT transmitter with a power at 2500 W through a Nautel NX4000TUB Antenna Tuning Unit (ATU).

The USCG contracted Allied Technology Group and R. Morgan Burrow and Associates in 1999 to design and implement a Pass Reject Diplexer Filter Network that would allow the DGPS and NAVTEX signal to be transmitted simultaneously through the same 299 foot tower at the Savannah site without either signal interfering with the other.

The antenna diplexer contains components that allow the two transmitters operating at these different frequencies to couple power to the same radiator but not to each other. Antenna diplexing at MF was accomplished using low-loss pass reject filters built with discrete reactive components. These filters are comprised of a pole-zero, series-pass, parallel-reject network, where the zero represents a low-impedance path through the series-resonant branch of the circuit tuned to the desired pass frequency. The pole represents high impedance at the undesired frequency presented by the parallel resonant combination of a variable reactance connected across the tuned series resonant circuit. A high reject ratio is desirable to block the higher frequency from entering the low frequency transmitter and vice versa.[3]

The final diplexer implemented at the Savannah NDGPS site consists of straightforward pole-zero network elements. The DGPS portion, looking from the transmitter to the tower, needed the SAC coupler/diplexer network to match to a final impedance of:

Z = 8.0 ohms - j 17.7 ohms at 900 W (319 kHz)

The NAVTEX portion as seen from the transmitter to the tower needed the NAUTEL coupler/diplexer network to match to:

Z = 38.5 ohms + 237.9 ohms at 2500 W (518 kHz)

The site has operated steadily since 1999 with a DGPS effective radiated power of nearly 400 W and NAVTEX effective radiated power at about 1200 W.

Loran

LORAN-C is a low frequency (LF) radio navigation aid operating in the 90-110 kHz radio spectrum, centered on 100 kHz. Although primarily employed for maritime and aviation navigation, LORAN-C transmissions are increasingly used for frequency reference, precision timing, and communications. LORAN-C had its beginnings in 1952, having evolved from the LORAN-A system originally developed for military use in the early 1940's and the NAVAGLOBE LF system developed in 1945. In 1974, it was selected as the federal radio navigation system for the Coastal Confluence Zone. Subsequently, the Federal Aviation Administration (FAA) has designated LORAN-C as a supplementary system in the National Airspace System (NAS). The North American LORAN-C system, a joint operation between the USCG and the Canadian Coast Guard, consists of 29 transmitting stations, 29 monitor stations, and three control stations. Although not included as part of the NAS, an international agreement also links a portion of the United States LORAN-C and Russian Chayka (LORAN) systems.

Three types of transmitting antennas, or towers, are currently in use in the North American LORAN-C system: Top-Loaded Monopole (TLM), Sectionalized LORAN Tower (SLT), and the Top Inverted Pyramid (TIP). **(Figure 2)** shows a TLM antenna. The TLM is composed of three major parts: the antenna, the top-loading elements (TLEs), and the counterpoise. The upper half of a TLM is one half of a center fed dipole antenna. There are between six and 24 TLEs attached at the top of the TLM. The ends of the TLE are insulated with fiberglass strain insulators and are supported by the TLE support guys. Top loading increases the capacitance of the antenna to ground thereby increasing the bandwidth. Top loading also increases the effective height of the antenna resulting in greater efficiency. TLMs are "hot", i.e. the structure itself is the antenna. Therefore a base insulator insulates the monopole from the ground. Because antennas are seldom placed over a perfect ground, the imperfect conductivity of the earth brings about changes in both input impedance of the antenna and the radiation pattern.

A counterpoise, or ground screen, is typically a series of wires placed at specific intervals that radiate outward symmetrically from the base of the antenna. The counterpoise provides a more homogonous ground for the antenna. Presently, the TLM configuration was chosen for co-location proof of concept testing.

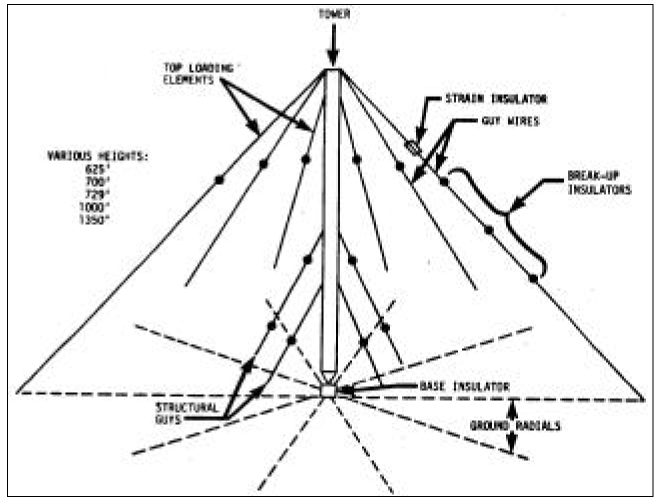

Figure 2: Top-Loaded Monopole (TLM) Antenna

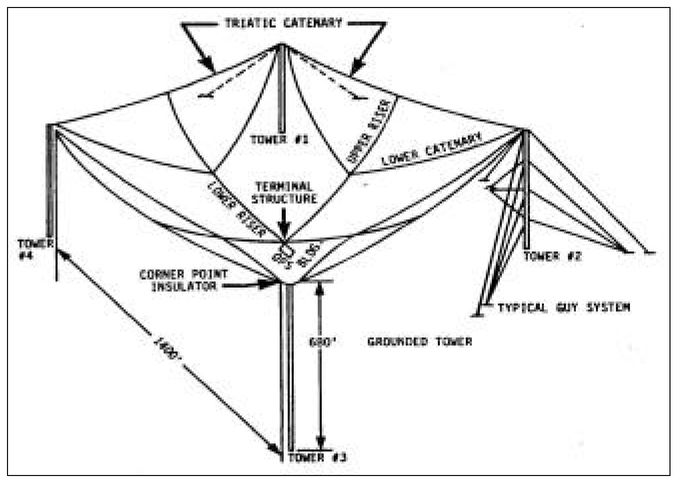

Figure 3: Sectionalized LORAN Tower (SLT) Antenna

(Figure 3) shows the SLT antenna, one of two multi-tower arrays (MTAs) used to transmit LORAN-C signals.

(Figure 4) shows the TIP antenna, the second type of MTA used to transmit LORAN-C signals. The differences between these antennas include: tower height, spacing between towers, and the design of the top hat. Note that the effect of these differences in mechanical design results in considerable differences in electrical characteristics.

Table (1) depicts some of the electrical characteristics among the various tower types in the US and Canadian LORAN-C antenna inventories.

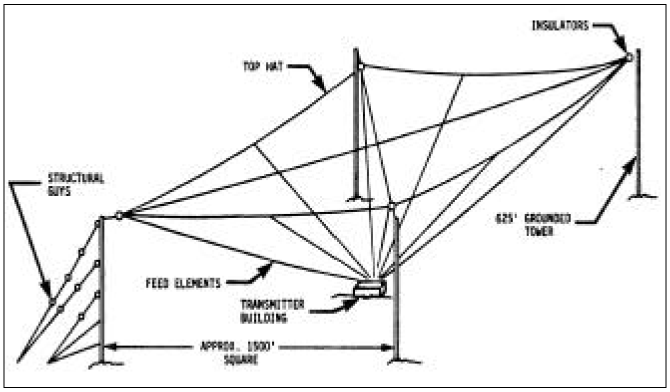

Figure 4: Top Inverted Pyramid (TIP) Antenna

Co-located LORAN-C and DGPS transmitters could potentially share transmit antennas. One method is to simply share sections of the tower structure, thereby configuring a dual-purpose antenna. Another method is to share use of the active elements of the antenna tower itself through diplexing. We will not provide an extensive discussion of the impact of diplexing on the characteristics of the LORAN-C signal because the current research effort is focused on co-location.

LORAN-C signals are precisely defined in the USCG Commandant Instruction COMDTINST M16562.4A, “Specification of the Transmitted LORAN-C Signal”. Additional clarifying information is also available in Wild Goose Association Publication No. 1/1976, “LORAN-C System Characterization”. Because LORAN-C transmissions are used for multi-modal purposes (navigation, timing, communications), the impact of co-location on each mode should be carefully analyzed.

Tower Type	Number in USA	Number in Canada	Characteristic Impedance (ohms)	dX/dF Slope (ohms/kHz)	Number of Top Loading Elements
500-FT TLM	0	1			
625-FT TLM	8	2	2.5 - j25	2.7	24 EA, 600'
700-FT TLM	8	0	4.0 - j23	3.0	12 EA, 740'
720-FT TLM	1	0			
721-FT TLM	0	1			
850-FT TLM	0	1			
1350-FT TLM	1	0	16.8 - j37	4.4	6 EA, 550'
SLT	5	0	3.3 - j15	1.2	None
TIP	1	0	4.6 - j13		None

Table (1) : LORAN Antenna Electrical Characteristics

Navigation. The power that a LORAN-C station radiates directly determines the coverage area with which the transmission will provide the desired level of navigation accuracy. The specification of peak-radiated power for LORAN-C transmitted signals varies depending on the application. Those stations presently operating in the United States have radiated power specifications ranging from 340 kW to as high as 1440 kW radiated peak power. The co-location effects must not significantly reduce the radiated power level, or any power level decreases must be mitigated through increasing the transmitted output power. Additionally, there should be no signal distortion effects (timing or frequency), on the local equipment cycle compensation loops that result in degraded navigation signals to the LORAN-C user community.

Timing. The North American LORAN-C system has an installed base of 101 HP-5071A primary cesium-beam frequency standards. LORAN-C is a Stratrum-1 Master primary Reference Source for timing. Co-location should not degrade the precision time reference capability of the LORAN-C signal.

Communications. Although originally designed for navigation purposes, the LORAN-C system transmissions are an effective method of conducting long distance communications. The FAA is currently funding a USCG initiative to study the use of LORAN-C as a "high-speed" data channel for providing the 500-bps GPS Wide Area Augmentation System (WAAS) differential correction and data integrity messages especially in the high latitudes of Alaska.**4** In this context, "high" speed is with respect to the speeds previously attainable using the LF LORAN signal. High-speed communication requires precision manipulation of the frequency of the LORAN-C signal within the pulse itself. Co-location must not deleteriously impact the capability of LORAN-C to provide WAAS messages.

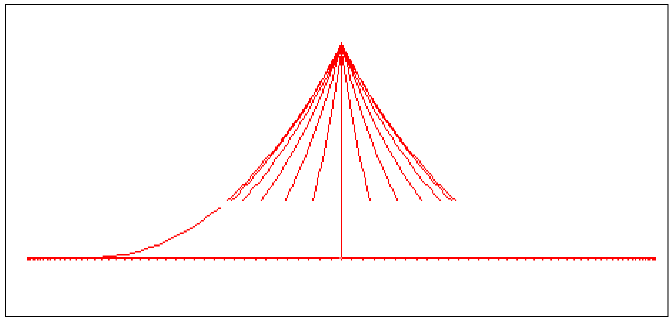

Figure 6: Computer Model of LORAN Tower with DGPS Modification

Co-Location Methodology

The USCG LSU in Wildwood, NJ has a 625' TLM antenna that can be used for real world testing. Members of the DGPS RF NWG traveled to LSU to reconfigure a TLE and collect data. **(Figure 5)** shows how the guy portion of the TLE was changed and Alumoweld was inserted to replace the steel cable. Prior to this visit, the USCG Academy was working to model the LSU tower and the effect of altering the TLE. This model was analyzed using the powerful antenna modeling software GNEC. **(Figure 6)** shows the graphical representation of the computer model that was generated.

Professor McKaughan and Cadet McCarter

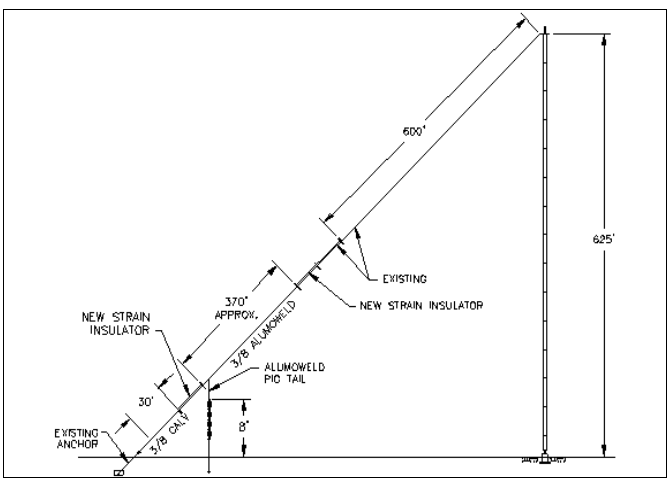

Figure 5: LSU Tower TLE Reconfiguration

The actual measured results closely approximated what the modeling predicted **(Table 2)**. The real part (resistive) of the actual reading was different due to the model only included the LORAN antenna ground plane. The RF NWG members installed a 20 ft by 20 ft copper mesh with several ground rods and tied it to two of the LORAN antenna ground radials. This reduced the ground loss portion of the overall antenna resistance.

	Frequency	Impedance
Model	300 kHz	45.8 – j420
Actual	295 kHz	18.25 – j480

Table (2:) Modeled Versus Actual Measurements at TLE

Proof-Of-Concept Test Location at LSU

Overall the values were very promising. While on site, the LORAN transmitter was energized and voltage measured and recorded at the feed point for the DGPS antenna. The induced LORAN RF was measured at approximately 16 kilo Volts (kV) peak-to peak. DGPS reference stations and integrity monitors were set up and tested at a location not far from the base of the LORAN tower. While the transmitter was broadcasting, there seemed to be no significant impact on the ability of the receivers to track satellites or provide DGPS corrections. The receivers were connected to a data logging laptop computer and left at LSU to evaluate any GPS masking issues that may occur due to the LORAN tower structure obstructing the sky view. The equipment was recently returned to C2CEN and analysis of the data is pending.

LT Parsons and CWO Manley

A portable 100-watt DGPS transmitter was connected to the DGPS antenna using a Starlink CP3000 coupler. The coupler was tuned to match the antenna and the LORAN transmitter was energized. The 16 KV of induced LORAN RF had no effect on the DGPS coupler or transmitter. The procedure was repeated using a Southern Avionics coupler. Again the LORAN induced RF had no negative effects on the DGPS equipment. Based on previous experience, it was felt that the DGPS antenna in close proximity to the steel structure of the LORAN tower would cause significant distortion of the radiated pattern.5 In some instances directionality is advantageous. For instance, the signal from sites located close to the Canadian border cannot interfere with the Canadian aero-beacons. By choosing the right TLE, the signal can be minimized or maximized in a given direction. The USCG Academy modeled the effects and the results are presented in **(Figure 7)**. A normal radiated pattern would extend equally in all directions discounting the effect of ground conductivity and terrain. The different colors in the figure indicate different take off angles measured from the ground towards the tower at which the radiation pattern has been measured. During the testing at LSU, an aircraft was contracted and DGPS field strength measuring equipment temporarily installed. The aircraft flew two circles around the LORAN tower, at a radius of two and ten miles. The field strength data is being analyzed and compared to the model predictions.

The concern with co-locating DGPS at LORAN stations has concentrated on finding any negative impacts of the high power LORAN transmitter of the DGPS signal. Since we saw none, we started to look at the effect of the DGPS signal on the LORAN operations. Discounting that the portable DGPS transmitter was limited to 100 watts; we saw no bearing on timing or pulse shape of the broadcast LORAN signal.

NEXT STEP

Although the on-air proof-of-concept testing was successful, some unanswered questions remain. What effect on the LORAN signal would occur if a 1000-watt DGPS transmitter were used? What effect of the polarization of the antenna leaning at an angle will have on the induced ground wave? How can the DGPS antenna be modified to maximize efficiency? How will the equipment hold up long term to the effect of the induced LORAN? To answer these questions another test should occur. This test should be geared more toward a long-term field test vice proof-of-concept. Based on final results and lessons learned, the techniques developed will be used in the future to examine possible DGPS antenna configurations for the SLT and TIP tower LORAN-C stations. Developing a solution for SLT and TIP sites should not be as challenging since the tower structure at those sites is not energized as part of the LORAN antenna. There are several options available ranging from isolating the tower by jacking it up and installing a base insulator or simply attaching a folded monopole antenna to the structure and isolating it.

BENEFITS

Why bother with looking for a co-location solution? In addition to savings in actual construction costs, there would be a resulting savings in the project timeline. Two new NDGPS sites that were recently built took well over two years to go through the process from site selection to the beginning of actual construction. Once a potential site is selected, a site survey must take place to make sure the property is technically suitable as a DGPS site. The environmental history of the site must be researched as well as the future environmental impact of building the DGPS site must be investigated. Once all clearances occur, a lease must be negotiated with the landowner or government agency that owns the property. Modifying an existing LORAN-C tower to broadcast the DGPS signal would eliminate most, if not all, of this process.

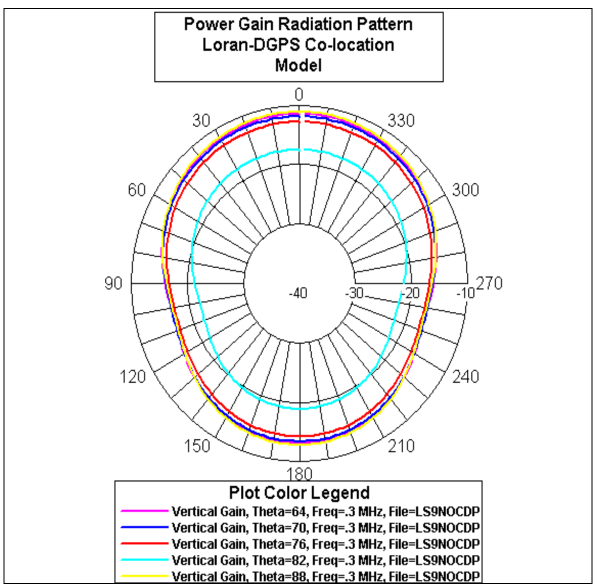

Figure 7: Theoretical Distortion of the Radiated Pattern of a Co-located LORAN and DGPS Antenna

Another benefit of co-location is the potential for increased signal availability. Currently when an unmanned DGPS site has an equipment failure, technicians must be dispatched to the site from locations very far away just to investigate the problem. In the current LORAN-C station model, USCG technicians already on site could not only investigate any failures, they could periodically visually inspect the equipment to see if there are problems developing (coupler arcing, etc). Having technicians on site could not only prevent some failures but also greatly reduce the downtime when an actual equipment failure occurs. If LORAN stations are un-manned, the recall time for technicians would still be much less in compared to dispatching a nationwide support contractor.

All benefits stated have even more importance when we discuss building NDGPS sites in Alaska. We expect that the labor and material costs in Alaska are up to three times as much as they would be in the lower 48 states. The environmental and permitting process is expected to take 1-2 years longer than typically in the lower 48. The remoteness of the Alaskan sites provides additional maintenance challenges. By co-locating at the Alaskan LORAN stations, we could potentially reap in excess of one million dollars in savings per co-located site.

CONCLUSION

Co-location not only results in project (tax dollars) savings, it greatly reduces the timeline involved to get a new DGPS signal on air. In addition, having USCG technicians available on site would increase the signal availability by providing a more rapid response if the equipment experiences a failure. Due to the many potential benefits, final testing and implementation plans should proceed further.

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— D. B. Wolfe, LT John L. Hartline, M. W. Parsons, C2CEN
M. E. McKaughan, H. L. McCarter, USCGA, New London, CT
LCDR C. A. Schue, III (RET) WR Systems, Fairfax, VA

Integrated ATONIS/ Local Notice to Mariners Automation

-An Update-

The migration of data from a legacy application to its enchancement application is always considered a challenge. Migrating data from ATONIS/Automated Aid Positioning System (AAPS) to Integrated Aid to Navigation Information System (I-ATONIS) will be no different.

As reported in previous articles, I-ATONIS automates certain Marine Information (MI) reporting responsibilities. To accomplish this automation, I-ATONIS relies on a new database structure. The new database structure includes and relies on several new data fields. Planning for this new structure is a complex task. Two of our deployment challenges will be:

1) *populating data in new information areas and*
2) *ensuring data integrity in the current database*

First, several of the automated products available in I-ATONIS will require new data to supplement the data in the current ATONIS database. This new information may be static or it may vary from day to day or week to week. The Coast Guard must populate the database with this information in order to produce these automated MI products accurately. NAVCEN will work with G-OPN and Coast Guard District Aids to Navigation Offices (oans) as well as our technical staff at G-OCC and OSC-Martinsburg to work out data population standards and strategies.

Our second challenge, ensuring data integrity, although a time-consuming effort, is critical. We have been urging our district oan staffs to focus on improving the integrity of their ATONIS data.

Districts need not review their data alone, because of the USCG partnership with National Oceanic and Atmospheric Administration (NOAA), we have enlisted their help to assist us in the review of all charted information (i.e., aid positions and characteristics). The Marine Chart Division of NOAA's Office of Coast Survey has developed a web-based tool for ATONIS data review. NOAA is comparing the ATONIS Short Range Aids (SRA) data with their charted SRA data, and will report results through this interface. The SRA "owner", using the web-based tool, as well as ATON unit documentation, can review and help resolve noted anomalies. NAVCEN will work with the Districts (oans) and NOAA to develop the necessary interface and review procedures.

For both these efforts, we don't expect overnight results; but with this tool and perseverance, data should be more accurate while migrating to I-ATONIS.

—– Marie Sudik, NAVCEN

CGSIC 40th

Meeting Announced

September 22 - 24, 2002

Portland, Oregon

NAVCEN and the Electronic Charting Guidance Team

It has been a year and a half since the Coast Guard's Electronic Charting Guidance Team (ECGT) was chartered, and it continues to cultivate critical dialogue between the diverse Coast Guard and US government agency stakeholders impacted by the advent of electronic navigation technology. As of June 6th, the ECGT will have met six times, all here at NAVCEN, and each & every meeting seems to need longer than the scheduled 4 hours. CINCLANTFTLT has now joined the group, as Navy operators are interested in the approach the Coast Guard is taking on these complex issues.

NAVCEN has committed significant resources to this effort. With the spring 2001 reorganization, we modified our mission statement, adding;

"Provides a center of excellence and a Coast Guard focal point for Electronic Navigation technologies, including Radionavigation, Electronic Charting, Integrated Bridge Systems (IBS), Automatic Identification Systems (AIS), and associated emerging technologies."

And;

"Actively participates and represents the Coast Guard in national and international forums on navigation issues."

This new mission statement reflects a line of work that has been developing at NAVCEN for years. In partnership with C2CEN and other Coast Guard elements, NAVCEN represents the Coast Guard in developing and implementing national and international standards for electronic navigation, some of which formally go into effect with amendments to the International Convention for the Safety of Life at Sea (SOLAS) in July of 2002. SOLAS is an International Maritime Organization (IMO) publication, and the IMO is a United Nations agency. This work covers commercial vessels of certain classes engaged in international voyages. NAVCEN is also a leading participant in various other related standards, including those produced by the International Hydrographic Organization (IHO), the International Electrotechnical Commission (IEC), the Radio Technical Commission for Maritime Services (RTCM), and the International Standards Organization (ISO).

NAVCEN is the Coast Guard's operational nexus for the dissemination of marine information, in close partnership with the National Oceanographic and Atmospheric Administration (NOAA), the National Imagery and Mapping Agency (NIMA), and the Army Corps of Engineers (USACE). The Charting Branch acts as national coordinator for the 10 Local Notices to Mariners published weekly by the Coast Guard Districts, and publishes the Coast Guard Light Lists every year.

Away from the intense program priorities and budget battles at HQ, we can take a step back and try to look at the larger picture. This makes NAVCEN the logical choice for the ECGT's executive secretary. We also provide the location, facilitator, and administrative support to the ECGT.

NAVCEN either leads or participates in most ECGT projects like the USCG-NOAA Memorandum of Agreement for chart production and data-sharing, electronic navigation training, as well as facilitating inquiries into the regulations needed for this new way of operating in our waterways. Recently, a CG-USACE effort to share inland waterway aids to navigation information has gained momentum. NAVCEN helped draft and is CG point of contact for the related MOA, and is very much involved with helping the project along.

In the course of normal business, the Navigation Center frequently interacts with the USACE on Nationwide DGPS and charting, with NOAA and NIMA on Notices to Mariners and charting, with the Navigator of the Navy's office on navigation policy, and with many other agencies and governments on national and international navigation related issues. As importantly, NAVCEN is increasingly the Coast Guard's navigation interface for the public.

As operators of Omega (now discontinued), LORAN and DGPS have traditionally been a radio-navigation center. These new functions have truly transformed us into an integrated Navigation Center. Who better to coordinate the work of the Electronic Charting Guidance Team?

—— LT Daniel Mades

United States Coast Guard Navigation Center

-Mission-

The United States Coast Guard Navigation Center (NAVCEN) provides quality navigation services that promote safe transportation and support the commerce of the United States. Under the authority of 14 U.S.C. 81 and in support of the International Convention for the Safety of Life at Sea, NAVCEN is responsible for operating maritime radionavigation systems and disseminating navigation information. NAVCEN also plays a central role in facilitating the civil use of the Global Positioning System (GPS), in support of Department of Transportation goals.

NAVCEN operates and manages Coast Guard radionavigation systems from two sites - Alexandria, Virginia and Petaluma, California. With 29 transmitting and 2 control stations, the Loran - C system provides service in the continental United States and Alaska. Linked with Canadian and Russian transmitting stations, Loran - C serves marine, air, and land navigation, as well as precise timing and other scientific applications. The Maritime Differential Global Positioning System (DGPS) network of remote broadcast sites serves United States coastal areas, including the Great Lakes, Puerto Rico, much of Alaska, Hawaii and the Western River system, and provides the accuracy and performance to support harbor entrance and approach navigation. The Nationwide DGPS (NDGPS) service is expanding coverage of the Maritime DGPS service to the entire continental United States and greater portions of Alaska, and provides the accuracy and performance to support positive train control and other land applications. Currently, 73 broadcast sites provide differential corrections to maritime and inland users; 4 additional sites are scheduled for completion during the winter months of 2002.

Through operation of the Navigation Information Service (NIS), NAVCEN provides the public with information on navigation systems and other waterways safety topics. The 24- hour staff of the NIS uses the latest computer and Internet technologies to gather, process, and disseminate timely radionavigation system status, marine advisories, and other maritime information. NAVCEN also coordinates and manages the Civil GPS Service Interface Committee (CGSIC) as part of the Department of Transportation's initiative to integrate GPS use into civil sector applications. CGSIC is recognized world- wide as the forum for effective interaction between civil GPS users and United States government service providers.

As a center of navigation excellence, NAVCEN is proud to continue the Coast Guard's long tradition of supporting waterway safety and maritime commerce. Through the use of new technologies such as DGPS and NDGPS, NAVCEN will serve our nation's transportation needs well into the 21st century.

Contacting the Navigation Information Service (NIS)

Internet:
http://www.navcen.uscg.gov

E-Mail:
nisws@navcen.uscg.mil

GPS Status Recording:
Telephone: (703) 313-5907

WWV/WWVH Radio Broadcast:
WWV broadcasts by telephone or radio at 14-15 minutes past the hour and WWVH at 43-44 minutes past the hour.
Radio frequencies: 2.5, 5, 10, 15, & 20 MHz.
Telephone: (303) 499-7111

Write or Call:
Commanding Officer (NIS)
U.S. Coast Guard Navigation Center
7323 Telegraph Road
Alexandria, VA 22315-3998
Telephone: (703) 313-5900

Coast Guard SDL No. 137

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