CO-LOCATING DGPS AND LORAN TRANSMITTERS

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BIOGRAPHY

LT John L. Hartline graduated from the USCG Officer Candidate School (OCS), in Yorktown, VA in 1994 after serving 13 years as an electronics technician in the Coast Guard. He was awarded a B.S.E.E.T from Old Dominion University, Norfolk, VA in 1999. Since graduation he has been serving as the NDGPS Installation Manager at C2CEN. He departs the position this summer and will be assigned to Old Dominion University to complete a master’s degree program.

LT Michael W. Parsons is a 20-year Coast Guard radio navigation veteran. He recently completed service as the Western DGPS Operations Control Station Manager where he supervised operation of 27 remotely located DGPS sites in the Western United States, Alaska, and Hawaii. He is currently serving in a DGPS hardware-engineering role at the Coast Guard Command and Control Engineering Center in Portsmouth, VA.

Michael E. McKaughan, Ph. D. first taught electrical engineering at the Coast Guard Academy in 1974. He has been at the Academy continuously since 1983. He completed his Ph. D. at the University of Connecticut in 1989. Dr. McKaughan’s primary research interests have been in the area of computer modeling of electromagnetic structures and antennas. He has published conference papers covering various topics from LORAN-C antennas through shipboard VHF antennas.

H. Lars McCarter is a first class cadet at the United States Coast Guard Academy and a student in the Department of Electrical Engineering. His senior design project involves the computer aided modeling of DGPS antennas which has lead to work on this project.

Mr. Charles Schue is Vice-President of Information Technology for W R Systems, Ltd., in Fairfax, VA. In this capacity, he oversees a wide-range of software products and services including supply chain logistics, secure networks, personnel management systems, and public utility meter records systems. He also provides program, engineering, and maintenance services support to the Navy and Coast Guard for radio and inertial navigation systems. Prior to joining WRS, he served in the Coast Guard where he provided expertise in the modernization and maintenance of LORAN-C, DGPS, and VTS. He is currently an International LORAN Association Director and is Treasurer of the Washington DC Section of ION.
ABSTRACT

The U.S. Coast Guard is part of the U.S. Department of Transportation’s team to expand the maritime Differential Global Positioning System (DGPS) service into a national transportation safety system. The U.S. Coast Guard’s role is to implement a Nationwide DGPS (NDGPS) expansion effort to more than double the existing number of broadcast sites. The NDGPS system is designed to meet all surface transportation navigation requirements in the United States and in addition will provide double terrestrial DGPS coverage across the continental United States.

The DGPS system operates in the Medium Frequency (MF) band where efficient antenna systems are large and costly to build. As a cost saving measure, the NDGPS project team is researching the possibility of co-locating NDGPS sites at U.S. Coast Guard maintained LONG RANge Navigation (LORAN) stations. The co-location concept offers several desirable benefits including but not limited to: significant savings in construction costs (especially in Alaska), reduced project timeline to acquire property, reduced environmental impact, and Coast Guard technicians on-site to maintain the NDGPS equipment.

The U.S. Coast Guard’s DGPS Radio Frequency (RF) Natural Working Group (NWG) initially proposed the concept of co-locating LORAN and DGPS signals on the same tower. This method was used successfully at the NDGPS site in Savannah, GA where the DGPS signal and a NAVTEX signal are both transmitted from a single antenna tower. Special antenna matching and isolation filters are used at this site. This technique is impractical at the LORAN sites because of potential degradation of the LORAN pulse shape. Using computer simulation and some creative brainstorming, three potential diplexing techniques are presented.

To reduce the potential for destructive interference of the LORAN signal, the RF NWG has investigated the possibility of using a single top-loading element (TLE) as the DGPS transmitting antenna. Additional isolation of the two signals should be possible by using the guy end that is connected to the TLE as the antenna for the DGPS signal. This portion of guy is 400 feet long and not an active element of the LORAN broadcast tower. Computer modeling and actual TLE guy impedance measurements are presented. These modeled and measured results indicate the merit of this approach. C2CEN has partnered with the U.S. Coast Guard Academy to build a matching network for the 400 feet TLE guy section and to perform proof-of-concept tests. Presently this effort will concentrate on the 625-foot and 700-foot top-loaded monopole LORAN antenna configurations. Additional schemes for using other LORAN tower configurations are presented. C2CEN, the Coast Guard Academy Electrical Engineering section, and the LORAN Support Unit (LSU) in Wildwood, NJ are working together on implementing this concept.

This paper reviews C2CEN’s methodology for computer modeling of both diplexing and co-location using the LORAN tower TLE guy as the DGPS antenna. The methodology leading to the final design is presented. Modeling and actual test results are presented plus plans for future implementation. Estimates of installation and operational savings are included.

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.

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.

![Figure (1): Typical NDGPS Broadcast Site Layout](image-url)
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. NAVTEX stations in the U.S. are operated by the USCG.\(^3\)

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, 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.\(^4\)

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:

\[
Z = 8.0 \text{ ohms} - j 17.7 \text{ ohms at } 900 \text{ W (319 kHz)}
\]

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

\[
Z = 38.5 \text{ ohms} + 237.9 \text{ ohms at } 2500 \text{ W (518 kHz)}
\]

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. Figure (2) shows the current configuration of the North American LORAN-C System.

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 (3) 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.

Figure (2): North American LORAN-C System

Figure (3): Top-Loaded Monopole (TLM) Antenna

Figure (4): Sectionalized LORAN Tower (SLT) Antenna
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 homogenous ground for the antenna. Presently, the TLM configuration was chosen for co-location proof of concept testing.

Figure (4) shows the SLT antenna, one of two multi-tower arrays (MTAs) used to transmit LORAN-C signals.

Figure (5) 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.

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.

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

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. We will instead address some areas requiring analysis during any co-location effort.

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

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. 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.

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 temporarily reconfigure a TLE and collect data. 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.

The actual measured results closely approximated what the modeling predicted (Table (2)). The real parts (resistive) of the actual readings were inconsistent with each other and with the model. The disparity was attributed to the unavailability of a good ground available when making the measurements.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Impedance</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 kHz</td>
<td>45.8 – j420</td>
</tr>
<tr>
<td>250 kHz</td>
<td>60 – j526</td>
</tr>
<tr>
<td>300 kHz</td>
<td>70 - j420</td>
</tr>
<tr>
<td>350 kHz</td>
<td>61 - j322</td>
</tr>
</tbody>
</table>

Table (2): Modeled Versus Actual Measurements at TLE

Overall the values were very promising. While on site, the TLE was lowered and jumpers installed around all the ceramic insulators to emulate a 400-foot antenna. The bottom end of the reconfigured TLE was attached to a Starlink CP3000 coupler and was able to match to it. Once all measurements were recorded, the LORAN transmitter was brought online at full power. The induced LORAN RF was measured at approximately 16 kilo Volts (kV) peak-to-peak. It could not be determined how much of the LORAN energy was induced and how much may have bled over the fiberglass strain insulator that separated the DGPS antenna from the active LORAN portion. Once all measurements were completed, the TLE was returned to its normal configuration. 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. In short, there were no obvious showstoppers to cause a no-go decision.

On a subsequent visit to LSU, a tower contractor installed a more permanent TLE reconfiguration. Figure (7) shows how the guy portion of the TLE was changed and Alumoweld was inserted to replace the steel cable. An additional fiberglass strain insulator was installed to see if it reduced the amount of LORAN RF measured on the DGPS antenna.
When the LORAN transmitter was energized, approximately 14 kV peak-to-peak of LORAN energy was measured. This indicates that the additional strain insulator is not warranted since the majority of all the energy appears to be induced into the DGPS antenna.

The USCG Academy personnel went to work designing a filter network that would help to reduce the LORAN energy that would be seen by the DGPS coupler on the antenna. Modeling of the filter shows results that would cause losses in the DGPS signal of approximately 50 percent. Because of this, the decision was made to first test without the use of any additional matching network external to what is already provided by the Starlink coupler.

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. In some instances directivity 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 (8). 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. In addition impedance measurements for different frequencies have been determined and were used in the design of the filter network for the antenna coupler.

The next step of collecting real results is scheduled to occur in February 2002. 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.

**IMPLEMENTATION AND COST BENEFIT**

The DGPS RF NWG is looking at various plans on how to implement a co-location for long term field-testing. Although many approaches are available, the simplest plan is also the most cost effective. A standard DGPS 19” equipment rack could be installed in the operations room of a LORAN-C station. The DGPS transmitter, which also occupies a 19” rack, would be installed in the station’s transmitter room. Reference station and integrity monitor antennas could be mounted on the roof of the building as long as satellite visibility was not severely impacted by the close proximity of the broadcast tower.

In the cost analysis, we have assumed installing reference masts for these antennas would be necessary. Conduit would have to be installed from the building out to the end of the TLE where a pole-mounted coupler would be installed. The TLE would have to be lowered and modified to become the DGPS antenna.

Although many towers, shelters, generators, and other equipment were transferred to the USCG from the USAF when the GWEN system was decommissioned, there are not enough supplies to build all the required new NDGPS sites. Because the LORAN-C stations have stable back-up power, existing buildings, voice and data communications and a tower in place, co-location allows these install assets to be saved for future use. In the cost benefit analysis, these items have been identified as a savings, although it is understood that the actual savings from the items transferred from the USAF would take place in the future as cost avoidance. Table (3) highlights potential savings of co-location at a LORAN-C station in the lower 48 states.
Figure (8): Theoretical Distortion of the Radiated Pattern of a Co-located LORAN and DGPS Antenna

<table>
<thead>
<tr>
<th>Nationwide DGPS Site</th>
<th>Newly Constructed Site</th>
<th>Co-Located Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>300' Antenna Installation</td>
<td>Labor</td>
<td>$60,000.00</td>
</tr>
<tr>
<td>Ground and Foundations</td>
<td>Labor/Materials</td>
<td>$82,000.00</td>
</tr>
<tr>
<td>Fencing</td>
<td>Labor/Materials</td>
<td>$28,000.00</td>
</tr>
<tr>
<td>Trenching and Backfill</td>
<td>Labor/Materials</td>
<td>$23,000.00</td>
</tr>
<tr>
<td>Gravel</td>
<td>Labor/Materials</td>
<td>$18,000.00</td>
</tr>
<tr>
<td>Contractor Travel</td>
<td>Logistical</td>
<td>$11,395.00</td>
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<tr>
<td>Contractor Per Diem</td>
<td>Logistical</td>
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</tr>
<tr>
<td>Shipping Costs</td>
<td>Shipping</td>
<td>$45,356.00</td>
</tr>
<tr>
<td>Contractor Labor Costs</td>
<td>Labor</td>
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<tr>
<td>Equipment Hut</td>
<td>Materials</td>
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<tr>
<td>Generator Hut</td>
<td>Materials</td>
<td>$20,000.00</td>
</tr>
<tr>
<td>Generator 30 kW MILSPEC</td>
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<tr>
<td>Transfer Switch</td>
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<td>Antenna</td>
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<tr>
<td>Reference Station Antenna Masts</td>
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<td>Fuel Tank</td>
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</tr>
<tr>
<td><strong>Totals</strong></td>
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<td><strong>$652,866.00</strong></td>
</tr>
<tr>
<td><strong>Savings per site</strong></td>
<td></td>
<td><strong>$521,866.00</strong></td>
</tr>
</tbody>
</table>

Table (3): Cost Comparison of New Construction versus Co-location
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.

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.

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.

**NEXT STEP**

Although the on-air proof-of-concept testing was scheduled for completion in the fall of 2001, the postal anthrax scare resulted in delays in obtaining approval for a broadcast frequency. Regardless, all modeling and actual measurements indicate there are no major problems that would preclude further investigation towards co-location. An authorized frequency for testing has been approved and on-air testing at the USCG LSU site in late February, 2002 is scheduled. Finally, a long term field test should be performed at an operational LORAN-C station that remains on air 24 hours per day.

**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.

**REFERENCES**


6 Wolfe, D.B., Godfrey, D.J., Hartline, J.L., Manley, E.B., Coverage Analysis of NDGPS Broadcast Sites, September 2001