POTENTIAL BENEFITS AND RISKS OF CO-LOCATING DGPS WITH LORAN-C

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BIOGRAPHY

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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.

LTJG Chris Treib graduated from the Coast Guard Academy with a B.S.E.E. in 2000. He studied shipboard antenna modeling as a major senior design project under Professor McKaughan. He received his commission in 2000 and served as the Engineer Officer in Training on USCGC VENTUROUS home-ported in St. Petersburg, FL. He is currently modeling DGPS and Nationwide DGPS towers at the USCG Command and Control Engineering Center (C2CEN), Portsmouth VA.

CWO Eric Shofner is a 21-year Coast Guard communications and radio navigation system veteran. He has four years experience with DGPS systems, two years supporting the Vandenberg Air Force Base Maritime DGPS site (the former Point Arguello location), and two years with C2CEN's N/DGPS Support staff. CWO Shofner is currently working with the Engineering staff at C2CEN, involved primarily with land based DGPS transmitters, couplers, and antenna systems.

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 (N/DGPS) expansion effort to more than double the existing number of broadcast sites. The N/DGPS system is designed to meet all surface transportation navigation requirements in the United States and 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. The N/DGPS project team is researching the possibility of co-locating N/DGPS sites at U.S. Coast Guard maintained Long Range Navigation (LORAN) stations, as a cost saving measure. Previous Radio Frequency Working Group (RF WG) studies showed that the signals might be generated from the same transmitter. However, the filtering techniques required are cost prohibitive and difficult to support and maintain. The RF WG transitioned from diplexing methods to co-location methods—sharing geographic location and resources while transmitting two independent signals.

Co-location minimizes most of the risks encountered with diplexing, but risks are still present and must be accounted for when designing a solution. The most significant risks co-locating DGPS with LORAN are destructive signal interference, insufficient power sources, radiation safety, and single point of failure issues. Any one of these risks could make co-location undesirable by altering the existing LORAN signal and support.

By transmitting two radio navigation signals at one geographical location, the USCG will operate both systems more economically. Savings will be realized through reduced installation costs, maintenance, and energy. Installation savings are currently projected at approximately $500,000 per site while maintenance and energy savings prove to be substantial, but will vary from site to site.

The solution to co-locating DGPS signals with LORAN has been discussed at several RF WG meetings. Through free communication of knowledge, creativity, and the spirit of improving existing engineering solutions, the RF WG has developed several solutions that minimize the associated risks.

HISTORY

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 N/DGPS Broadcast Network. When completed, the nationwide broadcast network will consist of over 126 sites and provide a standardized signal for DGPS service throughout the United States. Planned uses of the N/DGPS network include positive train control, precision farming, smart vehicles, snow plow management, accurate waterway dredging, and improved 911 emergency response, an expansion of traditional DGPS uses which include harbor/harbor approach navigation, vessel tracking and buoy positioning. [1,2]

The implementation of N/DGPS 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 N/DGPS system uses identical reference station and integrity monitoring equipment as the maritime DGPS sites, the N/DGPS sites have several differences. These include an alternate transmitter option, larger, more efficient broadcast towers, and a robust, highly reliable back-up power system—the U.S. Air Force (USAF) Ground Wave Emergency Network (GWEN).

At the same time the N/DGPS project was gearing up, the USAF was in the process of decommissioning its 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 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 N/DGPS project, many broadcast coverage holes exist that require construction of new towers in those areas. Locating property that meets the requirements for these sites is challenging. Additionally, acquiring leases, the public notification process, and obtaining environmental clearances places considerable drain on project resources, and could take up to three years to install some sites. The costs associated with building a new site are also about three times that of converting an existing GWEN facility. During a meeting of the USCG's DGPS RF WG, 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 N/DGPS site in Savannah, GA.[3,4]

Diplexing DGPS with LORAN turned out to be much more challenging than diplexing with NAVTEX. The 1200-kilo-watt output power of a LORAN transmitter dwarfs the (100 to 1000 watt) output power 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 structurally 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 the large amount of LORAN RF at the DGPS transmitter.

A third option is to use a 'cold' portion of the LORAN tower—a part of the structure where current and radiation from LORAN are at a minimum. 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 diplexing to co-location.

BENEFITS OF CO-LOCATION

The LORAN system contains an extensive network of towers, providing coverage throughout the United States and most of the world. In particular, LORAN is especially concentrated in Alaska, where timing and resources are absolutely critical due to extreme weather conditions and lack of infrastructure. Overcoming these conditions will be key in achieving N/DGPS coverage and LORAN infrastructure provides an appealing advantage to installing N/DGPS sites from scratch. LORAN's widespread design makes it an ideal template for improving N/DGPS coverage. Since LORAN uses lower frequencies and naturally has a larger coverage area than N/DGPS. Thus, the proposed co-location project will use LORAN to augment the existing N/DGPS system. However, by co-locating N/DGPS with LORAN, existing resources may be leveraged to provide single, dual, or possibly tertiary coverage, improving the integrity of the N/DGPS system. By transmitting two radio navigation signals at one site, the USCG will operate both systems more economically, realizing maintenance man- hours, site installation, materials, maintenance, and energy costs savings.[1,2]

The N/DGPS system has realized the above savings with the GWEN conversion program. Incidentally, the GWEN towers are the N/DGPS highest performing tower, outperforming all other towers in efficiency, gain, and bandwidth. Since it is clearly the best tower, it is appropriate to select the 299-foot GWEN towers are the basis for comparison to any improvements for N/DGPS radiators. Performance should be expected to meet or exceed the GWEN towers because LORAN towers are at least 600 feet tall and the following alteration should use a considerable part of the tower. Associated grounding, tuning, and transmitting components will also be similar to those installed on the GWEN converted towers.[5]

A standard N/DGPS site installation typically costs $539,856 for materials and $113,010 for labor. By using an existing tower, the estimated cost would be $95,000 for materials and $36,000 for labor—a significant $521,866 savings for each site. The greatest savings are realized in property purchases/leases, antenna/feed wires, fencing, gravel/landscaping, and site preparation. A significant amount of time is also saved through the environmental approval process of obtaining permission to develop the land with environmental considerations. A shorter acquisition phase will result in timely nationwide implementation of the proposal. Co-locating DGPS with LORAN provides immediate up-front savings in time and money.[1]

The co-location of DGPS with LORAN also has significant long-term savings in terms of maintenance and energy. Corrective maintenance is almost always associated with an off –air condition caused by bad weather (high wind, icing, or a lightning strike). Since LORAN is an older system with larger towers, there is an existing system to combat the weather that could also protect DGPS components. There is also a readily available infrastructure (i.e. USCG personnel, buildings, support), allowing for faster confirmation of trouble reports from remotely controlled DGPS sites. Since both sites are located together, failure determination and correction will be quicker. Preventative maintenance could be easily managed to ensure either LORAN or DGPS is on air while the other system is being upgraded. This is important because N/DGPS is still in its beginning stages and as the USCG installs more sites, more is learned and applied to future installations through system-wide field changes. LORAN also requires off-air as it continues to improve its accuracy and availability. The collocation of both systems makes it easier to maintain and upgrade as technology continues to improve both navigation systems.

Co-location is expected to save energy. The USCG operates several electrically 'short' towers with heights of 90, 120, 150, and 299 feet. Towers under 200 feet have efficiencies ranging from 12%-30% and the 299-foot tower exceeds them with an efficiency of about 50%. By using a larger tower, the antennas are more efficient, have larger gain. Thus, as long as the DGPS signal uses at least 299 vertical feet of the LORAN tower, it will provide the same coverage with less power or more coverage with the same power than a standard N/DGPS broadcast site does. In this case, DGPS only provides 'usable', or accurate correction signals up to 200 miles due to spatial decorrelation, thus it is more prudent to use less power because existing configurations already provide satisfactory coverage. Co-location will allow power to be lowered, providing a reoccurring cost savings benefit to the American taxpayer. [5]

The benefits of co-locating DGPS with LORAN towers are readily apparent in installation and materials, maintenance, and energy costs. The uncountable benefits from the synergy created by placing two navigation systems at one location have only begun to surface and will only be appreciated well after the immense initial and recurring gains are achieved.

RISKS OF CO-LOCATION

Although the benefits of co-locating DGPS with LORAN are quiet substantial, they come with some associated risks. Most of the risks have been minimized by moving from the diplexing stage to the co-location stage but they must be recognized as forces which drive the design of the project. The most significant risks co-locating DGPS with LORAN are destructive signal interference, insufficient power sources, radiation safety, and single point of failure issues.

The LORAN signal consists of a chain of pulses with critical timing information encoded in each pulse. LORAN is very sensitive to the shape and the time delay of the pulses. When disrupted, the LORAN signal looses information, affecting the accuracy of the fix. If co-location produces this result, the design iteration will be considered a failure. The goal is to produce two viable means of navigation at one geographic site using 'cold' portions of the LORAN tower. History shows that both signals require extra filtering and network matching while attempting to use one antenna tower, which is the primary motivation for separating the signals at the transmitter/coupler level. Can the signals use the same ground system? Can the signals be propagated off the same tower without destructive interference? The confidence that each designed solution offers to these questions increases the chances of successful adoption and implementation

LORAN effectively radiates 1200 kilowatts—approximately 30 times that which DGPS radiates (~400 Watts). It is possible that adding an increased input power load of 33% to the AC power load LORAN broadcasts already sustain, could have devastating results, such as brown outs, signal loss, equipment/cable overheating, melted source trunks coming into the base, and class "C" fires. It will be important to work closely with LORAN personnel to ensure a proper power supply is available and the existing infrastructure can support both signals.

Supposing that enough input power is available, how will the high output power broadcast signals interact once airborne? How independent are the signals? Will the air be able to act as a suitable filter? A great deal of information of how the electromagnetic waves interact is still unknown and open for future discovery.

If LORAN and DGPS are co-located, the technicians supporting both systems will have to become aware of the radiation hazards and necessary precautions for both systems. For example, the minimum safe distance from a radiating DGPS tower with an output of 400 watts (typical) is 25 feet. However, even though LORAN towers put out 30 times more radiation, LORAN towers are considered safe to climb (assuming the climber is not a path to ground) while radiating because it does so at a lower frequency. Thus, a technician trained in LORAN safety might very well be in danger if a DGPS signal was being radiated within 25 feet of the tower. Placing the DGPS transmitter at the fringes of the LORAN tower and training both DGPS and LORAN technicians about different radiation hazards can best minimize this risk.

Robust engineering systems never have a single point of failure—there is always a back-up, parallel operation to give operators confidence that the system will never experience catastrophic failure, no matter how badly it is abused. Similarly, the more components a system two normally independent radio navigation systems share, the more likely both will fail if one fails. The first step in minimizing this risk has been from sharing a transmitter to sharing 'cold' portions of a radiator by moving from diplexing to co-location. Even though most weather systems will have the same effects on the systems whether they are in a co-location configuration or are physically separate but located nearby, there are statistical anomalies with each system showing different weaknesses. The LORAN tower may be more likely to be struck by lightening, but is also more likely to survive due to creative and effective lightening protection techniques such as Z-feeds, and spark-gaps. A DGPS tower may be less likely to be blown over by the wind since it is smaller and has less surface area. In any case, it is assumed that all things are equal and the weather factor is statistically equal. The human factor does not necessarily treat the systems as truly independent. Suppose a terrorist is interested in disrupting all means of navigation, causing maritime transportation to come to a screeching halt, possibly with environmental pollution, massive human casualties, not to mention the loss of millions of dollars. Both signals are vulnerable if the terrorist destroys the tower itself. The simple truth is that both radio navigational systems are in the same proverbial basket. The bigger picture looks at both entire systems, not just particular sites, to determine that a minimum of double coverage must exist such that a catastrophic failure of a single radiator or more is an acceptable reality.

The challenge ahead lies in designing a suitable arrangement where DGPS can share resources with LORAN to minimize the inherent risks of destructive signal interference, insufficient input power, radio hazard, and single point of failure issues. The design with most promise in minimizing these risks will be selected for prototyping and study.

CO-LOCATION RECOMMENDED SOLUTIONS

The solution to co-locating DGPS signals with LORAN has been discussed at several RF WG meetings. Through free communication of knowledge, creativity, and the spirit of improving existing engineering solutions, the RF WG has considered an out-lyre TLE design, skirt design, and an inside radiator design.

The out-lyre TLE design (Figure 1) is driven by the philosophy of keeping the transmitters as afar apart as possible to avoid placing both signals on the same radiator.

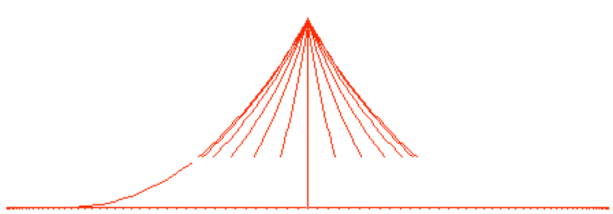

Figure 1: Outlyre TLE design

This is accomplished by unhooking a guy wire, placing an additional insulator on the LORAN TLE, re-attaching a strand to the base for support, and feeding the strand via a transmitter and tuning device.

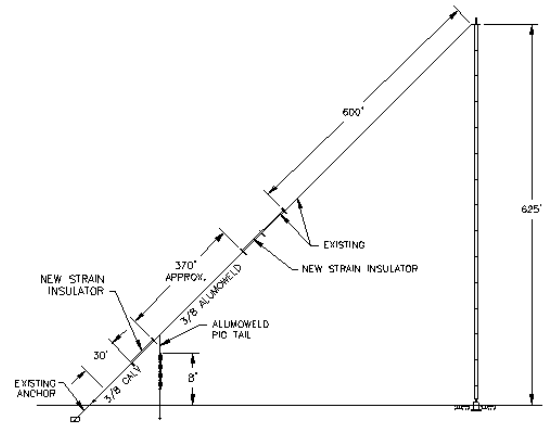

Figure 2: Outlyre TLE details

This concept has been prototyped in an experiment attaching a small transmitter (100 Watt input) to the out-lying, radiating TLE and recording data. The TLE was nearly omni-directional, but unfortunately, the cantinary at the base of the guy is significant enough to cause the radiator to become substantially horizontally polarized. Thus, the receiving antennas, which are vertically polarized, had significant gain issues. However, the DGPS signal did not interfere with the LORAN signal in any detectable manner. Further tests are underway to re-execute the test with a 1000-Watt transmitter. This will provide much more insight to the resources available at a LORAN tower and provide more substantial feedback to airborne electromagnetic interference with a more realistic scenario. It is more desirable to do this test with the current configuration despite known polarization problems because it is much safer to conduct the tests at the fringe of the LORAN tower.

The inside radiator design consists of attaching a single strand down the middle of the tower, producing a 500 foot vertical radiating wire. Obviously, the signals are going to be commingled in the air, if not on the actual structure. Radiation hazard becomes a serious factor because most LORAN tower climbing is conducted on the inside of the tower. The climber would encounter the stand for the majority of the climb, and maintenance would take significantly longer than if the radiator were remotely located. Another issue is the feasibility of any radiation coming from the inside of the cage. The MF waves are significantly long enough to potentially be shielded by the tower itself. Although this design shows promise in that it is simple and provides the greatest vertical length, it may not reach testing due to irreconcilable radiation hazards.

The skirt design looks like a big triangle and can best be shown in the graphic below.

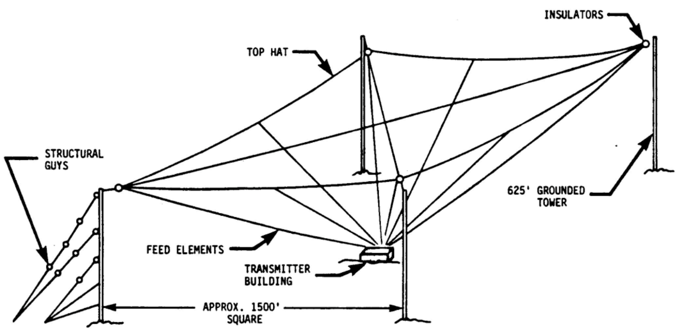

Figure 3: Skit Design

The advantage of this design is the radiator is kept away from the base of the tower, minimizing radiation hazards. It also improves vertical polarization and should place effective radiation at acceptable levels. The design is fairly complex and may cause structural concerns among USCG civil engineers. This design is offers the best parts of the previous two designs and is scheduled to be prototyped and tested.

The above suggestions to the problem will be studied by the RF WG and considered in finding the best radiator with the least risk in destroying the LORAN signal.

Conclusion

Co-location of N/DGPS with LORAN-C offers an improved solution to cultivate the vast benefits of sharing resources than diplexing the signals. The risks of destructive signal interference, insufficient power, radiation safety, and single point of failure are further minimized by adopting the co-location concept. Future plans include exploration of both RF signals at realistic levels and improving coverage through alternative designs.

REFERENCES

[1]Hartline, J., Wolfe, D., Parsons, M., Co-Locating DGPS and LORAN Transmitters, September 2001.

[2]Wolfe, D., Judy, C., Haukkala, E., Godfrey, D., Engineering the World's Largest DGPS Network, September 2000.

[3]USCG Navigation Center, "NAVTEX Maritime Safety Broadcasts" 2001. http://www.navcen.uscg.gov/marcomms/gmdss/navtex.htm (2 May 2001)

[3]Burrow, R., Rains, J., Simulation of DGPS and LORAN-C Signals Through Pass-Reject Diplexer Filter Networks, Engineering Report for USCG; 10 January 2001.

[4]Wolfe, D., Godfrey, D., Hartline, J., Manley, E., Coverage Analysis of N/DGPS Broadcast Sites, September 2001.