The Next Generation LF Transmitter and its Impact on Loran, eLoran, and Tactical (e)Loran Systems

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Biography

Charles A. "Chuck" Schue is co-founder and President of UrsaNav, Inc. a diversified engineering and IT solutions company headquartered in the United States. Mr. Schue served for 26 years in the U.S. Coast Guard, where his expertise was radio navigation systems. He holds Masters Degrees in Electrical Engineering from the Naval Postgraduate School; Engineering Management from Western New England College; and Business Administration from George Mason University. He is also a Certified Quality Engineer. Mr. Schue serves as Chairman of the Washington, DC Section of the Institute of Navigation and is on the board of the International Loran Association. He is a Private Sector Board Member of the Hampton Roads Military and Federal Facilities Alliance, and is an Advisory Board member of the George Mason University Executive School of Management.

Abstract

In a previous paper presented at the International Loran Association (ILA33) Technical Symposium in Tokyo, Japan, and entitled "Low Cost Digitally Enhanced Loran for Tactical Applications (LC DELTA)", we explored the concept of a modern tactical Loran system. [1] Because of very recent advances in Low-Frequency (LF) transmitter technology, we can now go beyond conceptualization. We can actually construct and field a LF position, navigation, timing (PNT), and data (PNT&D) system that:

- is easy and quick to install,
- has significantly reduced Size, Weight, and (Input) Power (SWAP),
- is exceptionally easy to operate and maintain,
- has high efficiency and very high reliability,
- requires no, or very limited, external cooling,
- includes inherent redundancy and soft-fail capability, and
- is cost effective, even in low order quantities.

This paper introduces the Next Generation LF Transmitter as the game-changing technology that is required at the core of a modern LF system. The Next Generation LF Transmitter is capable of supporting multiple missions (e.g., Loran, eLoran, Tactical Loran, emergency/data communications, subsurface/submarine broadcast), multiple modes (e.g., aviation, maritime, land mobile, location based, time & frequency), and multiple signal formats (e.g., Pulse Position Modulation, Supernumary Interpulse Modulation, and Intrapulse Frequency or Amplitude Modulation).

Key Words

Position, navigation, timing, data, tactical, Loran, eLoran, critical infrastructure protection, legacy transformation, low frequency.

1.0 Introduction

1.1 What is Loran*? Simply put, Loran is the traditional navigation system developed in the 1940's and most commonly referred to as Loran-C or "standard" Loran. Still in use in most parts of the northern hemisphere, standard Loran provides position, navigation, and timing solutions from "chains" of stations to users with operating receivers in "paired-station" mode. The traditional Loran service provides accurate, all-weather PNT services, independent of, and complementary to Global Navigation Satellite Systems, such as GPS, Galileo, or GLONASS. Loran is not as precise as GPS, but its one-third mile accuracy is better over a much larger area than any other ground-based alternative. [2] Most modern Loran stations provide improved accuracy, integrity, continuity, and availability performance than published by service providers. Several countries have identified Loran as the best backup for all modes of transportation. [3]

1.2 What is eLoran? Enhanced Loran, or eLoran, is a modernized and vastly improved version of standard Loran. At the core of a 21st century eLoran station is recapitalized infrastructure, and tremendously upgraded and modernized technology. Technology transformation includes major improvements to transmitters, timing and frequency equipment, communications networks, antennas, and control functionality. However, the key difference between the eLoran transmitted signal and the traditional Loran-C signal is the addition of a data channel. The data channel conveys corrections, warnings, and signal integrity information to the user's receiver via the eLoran transmission. [4] The data channel can take several forms. The United States is researching versions of a *Loran Data Channel*, and other nations are testing *Eurofix*. As of this writing, no standardized international data channel method has been selected. However, if correctly designed, the PNT portion of the eLoran system can be de-coupled from the D(ata) portion, effectively ensuring that regional service providers implement the data channel solution that best fits their user community requirements.

The United States has designated eLoran as a national system that will:

- Complement the GPS in the event of an outage or disruption in service; and
- Mitigate any safety, security, or economic effect of a GPS outage or disruption. [5]

To broaden this definition to include the international community, eLoran must be an independent and complementary system that provides similar services as GNSS such that it can adequately serve as a "substitute" when GNSS is not available, irrespective of the cause or duration of the unavailability. eLoran is a modernization of the land-based Loran-C system and by its very nature operates independently of GNSS. eLoran provides similar continuous PNT services as GNSS but at different levels.

In stating that eLoran will provide "backup coverage" to GNSS, we must acknowledge the differences in the levels of service and designat eLoran as the appropriate system to meet its requirements in the event of a GNSS fault or failure.

Because neither Galileo nor GLONASS are fully operational as of this writing, I have elected to use GPS as my GNSS reference throughout this paper. eLoran "can provide a cross-modal radionavigation system backup or complement to GPS for civil aviation, maritime users, emergency services, and timing application." Recent tests have indicated that eLoran meets or exceeds the accuracy, availability, integrity, continuity, and coverage requirements necessary to achieve 8-20 meter maritime Harbor Entrance Approach (HEA) and aviation RNP 0.3 nm Non-Precision Approach (NPA) levels of performance. [6]

1.3 What is Tactical eLoran? Tactical Loran is not a new idea. Later in this section, we present four historical efforts to deploy versions of Tactical Loran, all of them successful for their designed purposes. However, technology has significantly improved since the last tactical system was retired in the mid 1980s. Recent work in transmitting, timing, receiving, and ancillary equipment technology have not simply postulated, but have proven that Tactical *eLoran* is a viable means to provide PNT&D capability across multiple modes.

1.4 What are the basic requirements for Tactical eLoran? Because a Tactical Loran systems would be a subset of a Tactical eLoran system, this paper will focus on the eLoran version. A Tactical eLoran system, depending upon its ultimate use, would be capable of providing fixed, en route, and terminal position, navigation, and timing solutions, along with any associated data channel capabilities to government and commercial users at a lower cost than installing a fixed system. Some of the basic requirements for a Tactical eLoran system are:

- rapid installation and de-installation,
- small Size, Weight, and (Input) Power (SWAIP) requirement,
- significantly lower cost than a fixed system,
- ease of use that supports unmanned operation,
- the capability for autonomous operation,
- piece-wise equivalent to fixed system in signal specification and enhanced transmission formats,
- no, or very limited, external cooling,
- an easily deployable configuration, and
- equivalent reliability and robustness to fixed system.

1.5 What has been done in the past?

1.5.1 Loran-D. Loran-D was a short range, high accuracy, low power, tactical system designed for use as a bombing aid by the United States Air Force in the 1960s and 1970s. [7] Its primary objective was to provide a quick reaction capability to establish or extend Loran-C or –D coverage. [8] The TRN-38 version, developed by Sperry Rand's Gyroscope Division in the late 1970s, used 15 "Cycle Generators" as the core of a "portable" transmitter capable of radiating 30 kW at rates up to 533 pulses per second into a 400-foot quick erecting TLM antenna. See Figure 1. The tactical antenna could be erected within 12 hours of arrival at a finished site. Otherwise, it took four people 60 hours to erect the tower, including base plate and ground plane installation. [9]

Figure 1: Sperry Loran-D Transmitter. [9]

1.5.2 Air Transportable Loran System. In the 1960s, the U.S. Department of Defense funded development of the Air Transportable Loran System (ATLS), commonly known as “Atlas”. ATLS was a complete, integrated Loran-C station, including everything from power generation through a full-sized (625’ TLM) transmitting antenna that could be loaded into a C-130 aircraft for transport worldwide. One ATLS installation at Loran-C Station Lampedusa, Italy was supposed to have been “temporary” yet it actually performed as an operational station until 1987, when it was finally replaced with a permanent tube-type transmitting station as part of a NATO project.

1.5.3 Saint Mary’s River Mini-Chain. The Saint Mary’s River provides the waterway connection between Lake Superior and Lake Huron on the border of Canada and the United States. The Saint Mary's River was the navigation choke point for bulk cargo vessels, 600 to 1000 feet in length, that connect western Lake Superior product ports with the Lake Huron and Lake Michigan industrial centers. Economics of the steel industry, coupled with winter ice closure of the Saint Mary's River, had driven the construction of iron ore bulk vessels to the maximum length, beam, and draft physically capable of navigation through the narrow locks and rock-cut channels that characterize the waterway. [11]

In the mid-1970s, the U.S. Coast Guard determined the need for, and deployed, an experimental local area navigation system along the Saint Mary’s River. The Saint Mary’s River Mini-Chain consisted of three stations straddling the border between the United States and Canada. [12] Each unmanned station consisted of a 2-Half-Cycle Generator version of Megapulse’ Solid-State Transmitter operated into a Rohn 45G 150-foot guyed antenna. The chain operated successfully from May 1979 through May 1980, and provided “position information to within 20 meters 2DRMS in the critical portions of the river when operated with relatively infrequent differential offsets.” [13]

1.5.4 Pulse/8. In 1974, Racal Positioning Systems, Ltd. developed a so-called Mini-Loran variant of Loran-C that used low power solid-state transmitters coupled into 300-foot antennas that radiated peak pulse power of 1 kW RMS over baseline lengths of about 350-400 nautical miles. The Pulse/8 systems were installed to aid in the seismic exploration of oil in the North Sea, the Gulf of Mexico, and the Java Sea. There were a total of 10 operational, unmanned Pulse/8 stations in 1986. With Pulse/8, Racal demonstrated that even at a 1 kW RMS radiated power (and with 1980’s receiver technology), usable signal strengths were achievable at ranges up to 400 nautical miles. Further, these systems were able to achieve repeatable fix accuracies often as good as 15 meters. [14]

1.6 Why eLoran? (e)Loran is inherently complementary to GPS. It is terrestrial rather than space-based. It operates in a very different frequency band and has dissimilar failure modes. From a security standpoint, hostile forces would find it hard to disrupt land-based and space-based infrastructures simultaneously. (e)Loran installations can, in most cases, be repaired or replaced repeatedly, whereas the consequences of any successful assault on a satellite infrastructure are likely to be prolonged. GPS signals remain vulnerable to jamming, despite improvements in countermeasures, whereas eLoran, with its strong, dispersed signals, large ground antennas and 90- to 110-kHz medium-wave operation, is thousands of times harder to jam. [2]

The operational requirements for a backup and redundant capability are based on disruption of PNT, most likely by interference. The impacts are not local. Typically, 200-300 miles radius from the interfering source characterizes the affected area. In a deliberate event, multiple interference locations can be anticipated. Another scenario of concern is the mobile and intermittent intentional interference, to avoid detection and apprehension. In this case, interference is a menacing, long-term disruptive event. Outages associated with GPS satellite failures, more commonly known as "brown-outs", would also cause a disruption. While safety can be maintained, the loss of GPS in the absence of a backup will cause significant economic disruption in many, if not, all critical infrastructure components simultaneously. [15]

The greatest deterrent to selecting GPS as a target is if the consequences of such an act go unnoticed or are so minor that the value as a target is diminished. This is the greatest value for a backup to GPS. So far, GPS has not been a deliberate target, principally because of legacy navigation aid redundancy. The first obligation for a backup is safety, followed by continuing to maintain close to the same capacity, denying GPS as a high-value target, and preserving our economy. [16]

A credible backup system is somewhat akin to a backup (reserve) parachute: it must be 100% available when we need it! Therefore, the technology underlying (e)Loran must be as robust, reliable, and affordable as possible while still meeting accuracy, integrity, continuity, and availability performance requirements specified by service providers.

2.0 The Next Generation LF Transmitter. Until recently, there were four generations of LF transmitters that could transmit (e)Loran. This paper does not include transmitters that were designed to transmit Russian Chayka or United States Air Force Loran-D, although the Next Generation LF Transmitter is fully capable of generating those signal formats as well.

2.1 First and Second Generations. The first two generations of Loran-capable transmitters were the AN/FPN-39 and AN/FPN-42 Tube-Type Transmitters (TTX). These were 1940's and 1950's vintage, vacuum-tube transmitters

2.2 Third Generation. The AN/FPN-44A and AN/FPN-44B Tube-Type Transmitter Sets are essentially equivalent third-generation, mid-1960's vintage, vacuum-tube transmitters. They are multi-stage, class B push-pull amplifiers, capable of providing over 600 kW of output power, given the optimum transmitter and antenna match. Each transmitter set included two *Transmitting Groups*, Group I and a Group II, thereby providing built-in redundancy in the event of a failure of one Group or the other. The Transmitter Set requires three-phase, 440 VAC input power, and the Groups share a common *Antenna Coupler*, through which the on-line Group is routed to the antenna, and the off-line Group is routed to the *Dummy Load*. The tubes in the Transmitting Groups are cooled using de-ionized water. A complex primary/secondary heat exchanger and radiator system transfers the waste heat from the tubes to the outside air. AN/FPN-44A transmitters are located at three Loran Stations (LORSTAs) in North America; the AN/FPN-44B transmitters are located at two LORSTAs.

2.3 Third Generation - Variant. The AN/FPN-45B Tube-Type Transmitter Set is the much larger cousin of the AN/FPN-44, also built in the mid-1960's. It has two additional amplifier sections in each Transmitting Group, and provides about four times the output power of the AN/FPN-44, after taking into consideration the type of transmitting antenna used. There are no AN/FPN-45 transmitters still in operation in the world.

2.4 Fourth Generation. The AN/FPN-64A Solid-State Transmitter Set (SSX) is a fourth-generation, mid-1970's vintage, solid-state transmitter consisting of many *Half-Cycle Generators* (HCG), each of which contributes a portion of the power output. This transmitter's design differs significantly from previous generations as it is not an amplifier. It develops the Loran pulse using pulse compression techniques. Megapulse, Inc. developed the AN/FPN-64 transmitter under a Research and Development contract for the U. S. Coast Guard, and the initial Pre-Production Prototype Transmitter (PPPT) version was installed at the Electronics Engineering Center in December 1976. Besides the HCG sections and the Output and Coupling Networks, the SSX includes a Prime Power Distribution Unit, a Fire Protection System, and a Control Console. The output power requirement is met by adding additional HCGs. Although the SSX is available in 8-HCG increments, only three versions are used in the North American Loran System. The AN/FPN-64A(V)1 is a 32-HCG version, the AN/FPN-64A(V)4 is a 56-HCG version, and the AN/FPN-64A(V)6 is a 16-HCG version. The SSX was designed as a *soft-fail* transmitter; modules can fail, yet the transmitter can remain operational while the modules are troubleshot or replaced. The SSX requires three-phase, 208 VAC input power, and is capable of providing over one megawatt of output power when terminated in a 700-foot TLM. The AN/FPN-64A series transmitters are located at 17 LORSTAs in North America

2.5 Fourth Generation - Variant. The commercial version of the AN/FPN-64A Solid-State Transmitter Set is the Accufix 6500. In 2001, Megapulse introduced the Accufix 7500 Solid-State Transmitter, known as the New SSX or NSSX. The Accufix 7500 is a smaller and more powerful upgrade of the

Accufix 6500 technology. According to their website, improvements are made to the Transmitter Control Subsystem and to the power section of the transmitter. There is also greater use of commercial off-the-shelf (COTS) components system-wide. [17] There are eight Accufix 7500 transmitters installed in North America, including the first article at the U.S. Coast Guard's Loran Support Unit.

2.6 Fifth (Next) Generation. The author had postulated that commercial AM broadcast technology might be adapted to transmit Loran. Based upon this premise, Mr. Hilmer Swanson, Chief Scientist at Harris Corporations' Broadcast Communications Division, used Harris DX technology to demonstrate the ability to transmit a Loran pulse into a 50-ohm load. Figure 2 is a representative Harris 10 kW Digitally Amplitude Modulated Transmitter. This feat was later accomplished by other AM broadcast vendors, including Nautel. However, this "brute-force" approach was never intended to overcome the complex problems associated with transmitting into a small-BW Loran antenna. It was simply a means of stimulating the pursuit of innovative Loran transmitting technology.

Figure 2: Harris 10 kW DX Digital AM Transmitter

3.0 Introducing the Next Generation LF Transmitter. Nautel, Inc. and UrsaNav, Inc. have worked over most of the past two years to develop transmitter technology that operates in the Loran band. This in and of itself is not innovative. However, the ability to transmit Loran into physically short antennas, with their associated significant reflected power, while setting an industry standard in reducing SWAIP *is* innovative. Nautel's patent-pending pulse power recovery technique forms the basis for this next generation technology. It allows their NL Series transmitters to achieve the exceptional efficiency and low maintenance overhead of their commercial RF broadcast transmitters.

3.1 Proof-of-Concept Development. Figure 3 shows a proof-of-concept NL Series transmitter during development at Nautel's facility in Halifax, NS, Canada. This 50 kW Effective Radiated Power (ERP) prototype transmitter was tested in April 2008 at over 600 PPS into a simulated 625-foot TLM antenna. Considerable testing was also done on combinations of North American rates, "problem" rates, such as 9610, and so-called "corner cases" such as Boise City, OK's 9610/8970 and Searchlight, NV's 9610/9940.

Figure 3: Proof-of-Concept at Halifax, NS

The NL Series sets a new standard for a next generation eLoran transmitter with outstanding performance, robust design, and operational ease, all packaged within the industry's most compact enclosure. With exceptional pulse control, efficiencies approaching 70 percent or better, unmatched levels of redundancy, and intuitive touch screen interface, the NL Series technology is truly innovative.

3.2 Core Technology. The building block of the NL Series is an RF amplifier with a peak power capability currently at 50 kW. Recent research indicates this capability may be increased two-fold, or more. Figure 5 shows a prototype RF amplifier module. The Class-D RF amplifier uses four transistors that are field-replaceable, extremely efficient, capable of operating at high power, and that generate minimal waste heat.

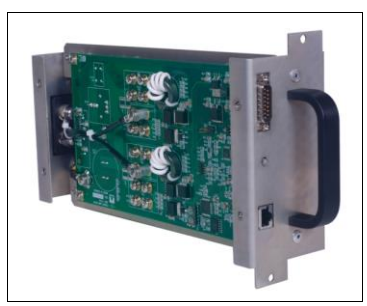

Figure 5: Nautel NL Series RF Amplifier Module

The NL Series is based upon proven commercial designs that are built to withstand harsh environments all over the world. Tens of millions of hours of real-world operational experience result in a design that has unparalleled performance and reliability. High reliability modules, coupled with soft-fail and hot-swappable technology, significantly reduces organizational-level sparing requirements. Experience fielding 5 MW CW transmitters ensures that NL Series eLoran transmitters are scalable to meet the highest conceivable power requirement.

The NL Series has exceptionally efficiency and low maintenance overhead, making it extremely cost effective to own and operate. Overall efficiency is typically 70 percent or better. High efficiency means less energy is wasted as heat, which reduces input power requirements, cooling, and ventilation costs.

NL Series transmitters are one-half to one-third the size of comparable high-power eLoran transmitters. Yet, even with this compact design, the NL Series offers easy and spacious access to all major serviceable components and modules.

As we all know, tall antennas invite lightning and static discharge that can devastate transmitters and their ancillary equipment. The NL Series includes the proper lightning protection designs accumulated from over 35 years of navigation and broadcast transmitter experience.

3.3 Key Components. Key components in the NL Series transmitters are fully redundant and hot-swappable. For example, the production model design would include built-in spare RF power amplifiers that are computer reprogrammable on the fly from spare to operational. Additionally, RF power amplifiers are hot-swappable with no impact on transmitter operational specifications. The NL Series offers:

- redundant, lightweight RF power amplifiers,
- redundant exciters,
- multiple parallel/redundant fans in each cabinet,
- redundant low-voltage power supplies,
- failsafe manual and remote control,
- redundant switch mode power supplies,
- redundant controllers,
- an easily deployable configuration, and

One of the key requirements of an (e)Loran transmitter is the ability to precisely control the pulse timing, frequency, and shape. The NL Series exciter section, which provides the coherent drive to the RF power amplifiers, builds a precisely calibrated (e)Loran pulse each time it is triggered. The exciter section is completely duplicated within the transmitter. Switching between operate and standby exciters is entirely transient-free.

Although the prototype transmitters use 208V, 3-phase, 4-wire input power, by simply changing the power transformer, the NL Series can operate over a wide range of input power.

3.4 Proof-of-Concept Testing. Proof-of-concept transmitters have been developed, including associated 625-foot TLM antenna simulators. Symmetricom's Timing and Frequency Equipment provides transmitter drive signals, including Multi-Pulse Trigger (MPT), Phase-Code Set, Phase-Code Reset, Local Interval, Phase Code Interval (PCI), Early MPT (EMPT), 100 kHz, and 5 MHz. Figure 6 shows some of the major components of the proof-of-concept transmitter.

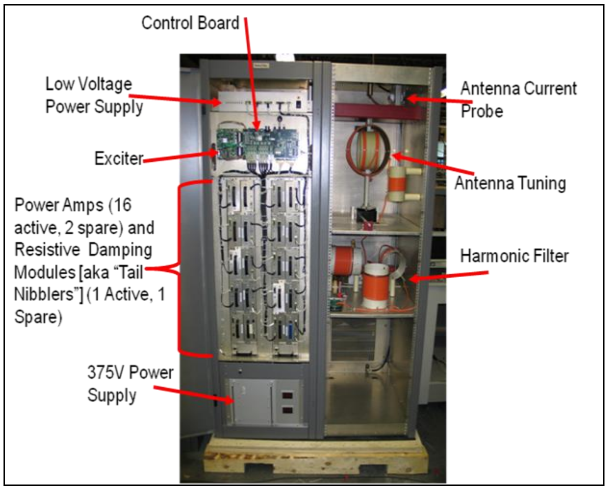

Figure 6: Nautel NL Series Proof-of-Concept

Comprehensive on-air testing of the proof-of-concept's ability to generate suitable eLoran signals into an actual 625-foot TLM was conducted at the USCG Loran Support Unit (LSU) in Wildwood, NJ. Independent test results are being reported separately. Figure 7 shows the proof-of-concept under test at the LSU.

Figure 7: Proof-of-Concept at Wildwood, NJ

3.5 Advanced User Interface. The production NL Series transmitter will feature a 17-inch color LCD Advanced User Interface (AUI) with a wide range of configurable displays. The AUI is touch screen, or keyboard and mouse controlled. Some of the AUI features include monitoring, reporting, analysis, and logging of:

- time domain characteristics,
- frequency domain characteristics,
- pulse shape characteristics,
- power,
- modulation, and
- module parameters and activity.

For example, the AUI would provide transistor temperatures on the RF power amplifiers and whether or not that particular amplifier was operational or a spare. Additionally, the AUI provides for local and remote access to all features using a web browser via any web-capable PC or handheld device. The touch-screen interface is implemented as a non-critical functional unit and may be completely removed from the system without affecting transmitter operation. A backup control interface provides redundant control capability in case of front panel computer system failure. Besides web based access, the NL Series also supports contact closure capability for both local and remote control. Figure 8 shows a representative AUI.

For the U.S. (e)Loran system, the AUI could replace many of the functions of the Remote Automated Integrated Loran (RAIL) and Equipment Control Monitor (ECM) systems. With some software design effort, the AUI could also provide interfaces to Loran Consolidated Control System (LCCS), New Loran Consolidated Control System (NLCCS), Control Center Brest (CCB), or similar remote command and control systems.

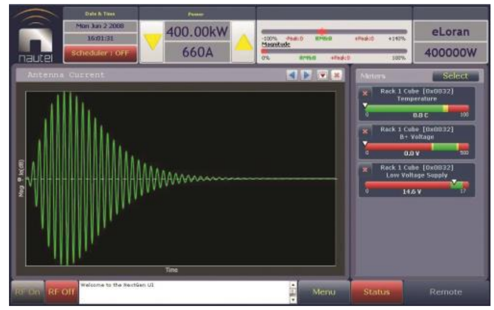

Figure 8: NL Series AUI.

3.6 Production Model. Figure 9 is a representation of a production 480 kW NL Series transmitter. This design is based upon using cabinet components from Nautel's production broadcast transmitters, such as the NX Series. When matched with the well-known 625-foot TLM antenna, a 480 kW ERP NL transmitter would have a *maximum* footprint of 12 feet long, three (3) feet deep, and seven (7) feet tall. Recent design changes indicate even this small footprint can be further reduced. Note that this is a fully redundant eLoran capable transmitter, effectively two transmitters in one enclosure.

Figure 9: 480 kW ERP NL Series Transmitter.

Once the final production NL Series design is determined, transmitters are expected to take less than 60 days to manufacture. Because many components and fabrication processes are shared with Nautel's other broadcast and navigation systems, maintenance and training for the NL Series will be similar, and there will be an existing network of technical personnel familiar with the underlying technology.

3.7 (e)Loran-in-a-Box (ELB). At this point, it is worth introducing the reader to the "(e)Loran-in-a-Box" concept. Because the NL Series has a significantly smaller SWAIP footprint than any previous (e)Loran transmitter, it is possible to construct an entire (e)Loran signal generation site within the confines of an ISO standard 20-foot container, or equivalent space. ISO containers are typically 20- or 40-feet long, eight (8) feet wide, and eight (8) or eight and one-half (8 or 8.5) feet tall.

A typical ELB solution would consist of the following components or “suite” of systems:

- Appropriately sized NL Series transmitter,
- Time Recovery & Signal Generation,
- Command, Control, Communications Capability,
- Ancillary equipment (i.e., HVAC), and
- Any desired (uninterruptible) backup power.

The ELB concept could drive historical, existing, or planned antenna configurations, depending upon the required ERP and deployability, including:

- 500-, 625-, 700-, 720, 850-, or 1350-foot TLM,
- Top-Inverted Pyramid (TIP),
- Sectionalized Loran Transmitting Antenna (SLT),
- 290- to 306-foot GWEN,
- “Antennas of Opportunity” (e.g., re-purposed AM antennas),
- 300-foot Tilt-up Tower (AN/TSA-17, or equivalent),
- 300-foot Goodyear Type or Birdair Type inflatable tower,
- Up to 300-foot Andrew Tower Corporation telescoping tower,
- 290-foot “jack-up”,
- Anthorn, Cumbria “T-type”,
- Tri-tethered, aerostat-, airship-, or balloon-supported, or
- Tri-tethered, Allsopp Helikite-supported.

Note that although the U.S. Ground Wave Emergency Network (GWEN) system was shut down in 1997, as part of its inventory several DARPA/Westinghouse 750-6000m tethered Aerostat-Augmented balloons were available capable of hoisting an antenna capable of broadcasting the high-powered 150 – 175 kHz GWEN transmissions. [18] This system, if still available, could be re-purposed to operate at 100 kHz and used for various (e)Loran applications.

If commercial prime power is not available, then prime generator, or combined power generation would most likely be housed in an appropriately sized separate container, possibly a QUADCON or TRICON.

Figure 10 shows the authors proposed ELB solution excerpted from the initial Loran Recapitalization Program briefing given to senior U.S. Coast Guard personnel in April 2000.

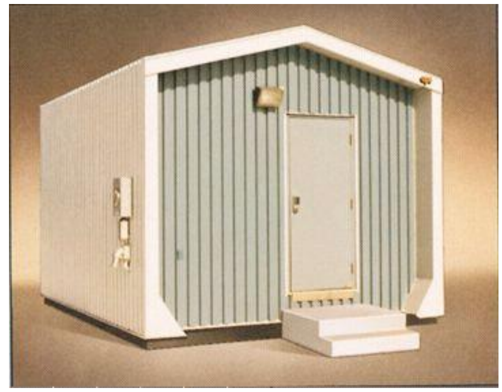

Figure 10: Proposed Un-Staffed Loran “Site”

Figures 11, 12, 13, and 14 show several versions of containers, enclosures, and trailers that could make up a modern-day ELB.

Figure 11: Thermo Bond Shelter

Figure 12: Shelter One Industrial Shelter

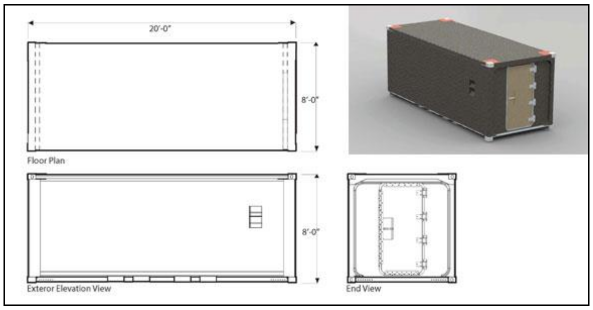

Figure 13: Alkan ISO Shelter


Figure 14: Gichner Trailerable ELB

4.0 The NL Series as a Loran, eLoran, or Tactical (e)Loran Solution We are all probably familiar with the various published documentation about the vulnerabilities and weaknesses of the GPS. In particular, this paper recognizes the existence of those publications but is not a primer on the subject. Readers are encouraged to review references [A] through [K] at the end of this paper as a sampling of widely available and credible discussions on the topic. Section 1.2 of this paper explains why eLoran is the best multi-modal backup and complement to the GPS. This section applies the Next Generation LF transmitter technology to solving Loran, eLoran, and tactical (e)Loran problems, whether used as a primary or backup solution. For the purposes of this discussion, Loran is considered the standard Loran-C system currently in operation in many northern hemisphere countries, eLoran is a modernized version of Loran that includes some method of data modulation, and tactical (e)Loran is a deployable version of Loran, eLoran, or some variant, including Loran-D.

4.1 Augmentation to Improve Poor Geometry. Although station location can be optimized for signal characteristics, in the past fiscal and geographic limitations often preclude us from capitalizing on optimum station placement. This sometimes results in less than optimum chain geometry and coverage. There are times when an improvement in geometry might be cost effective. This improvement could be the addition of a single station to address poor coverage, a short term requirement, or the installation of a small network of tactical stations to support a theater of operations. Because the Next Generation LF transmitter is easily scalable through a full-range of power requirements, a suitably-sized and economical transmitter could be provided for most conceivable applications.

4.2 Determining Optimum Station/Site Location or Testing Station Relocation. In this scenario, the Next Generation LF transmitter provides a low-cost capability to quickly and efficiently test whether or not a selected station/site is going to operate as predicted. For example, the U.S. Coast Guard is studying the feasibility of relocating the Port Clarence Loran-C Station to Nome, AK. The Next Generation LF transmitter could, depending on the antenna, be used to provide limited or complete area coverage from Nome during an evaluation or overlap period. In other countries that are looking to develop new or augment/extend existing (e)Loran service, a Next Generation (e)Loran transmitter would provide the core around which rigorous testing could be performed at minimal cost.

4.3 Additional Stations – Low to Middle Latitudes. Fiscal realities often limit the number of stations in a particular geographic area. A cheaper, smaller footprint alternative might allow for some novel additional stations. For example, would it be beneficial to improve offshore coverage by moving the X-ray baseline of the 9940 U.S. West Coast Chain from its current endpoint at Middletown, CA to the Farallon Islands 30 miles west of San Francisco? The Next Generation LF transmitter enables a more cost effective fielding of new stations.

Another example where a low power transmitter could be useful is in the area off the southeast coast of Florida. This area is characterized by:

- High Coast Guard operational interest because of illegal immigration and drug traffic,
- Large areas of shallow water (the Little and Great Bahama Banks) at long ranges from land requiring electronic navigation to avoid grounding (See Figure 15), and
- The lack of (e)Loran coverage because the most southeast station in the United States is at Jupiter, Florida.

Could an adversary possessing either better local knowledge or having shallower draft gain an advantage by denying the Coast Guard or other authorities the use of GPS? If so, the ability to rapidly establish (e)Loran coverage in the area could allow for safe operations. Figures 16 and 17 illustrate the (e)Loran coverage possible in that area when combining a 10 kW mini-(e)Loran transmitter either on land, vessel, or platform.

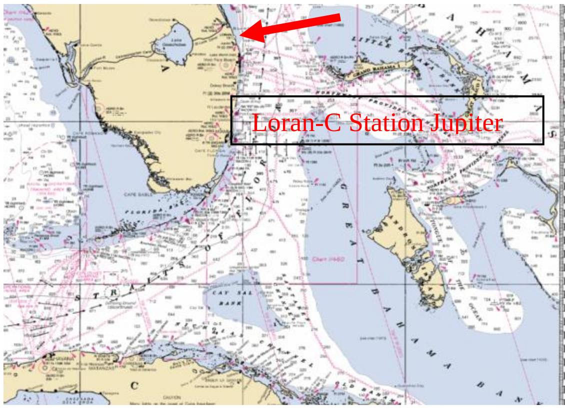

Figure 15: NOAA Chart 411 (Gulf of Mexico).

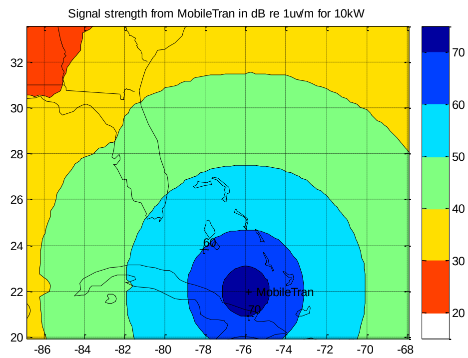

Figure 16

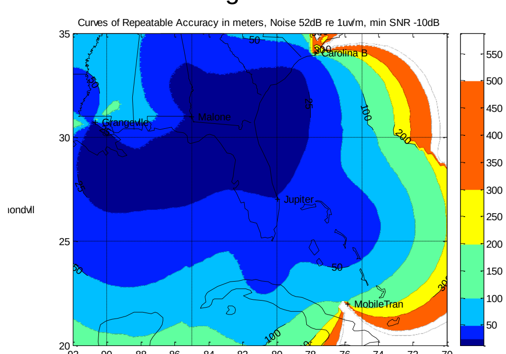

Figure 17

In the United States, it might also be possible to re-purpose Ground Wave Emergency Network (GWEN) sites as (e)Loran sites. Figure 18 shows the proximity of (e)Loran stations and GWEN sites in the CONUS. There are similar proximities in Alaska. Once the standard 300-foot GWEN antenna is modified for 100 kHz, it can easily be driven by a low-powered Next Generation (e)Loran transmitter. The combination of a re-purposed GWEN site and a Next Generation transmitter provides an efficient and economical option. Further, a GWEN site could be used as a very low-cost, alternative (e)Loran operational and engineering support facility. It would be especially suited as a Government-Owned, Contractor-Operated (GOCO) site, such as the U.S. Naval Communications and Telecommunications Area Master Station (NCTAMS) sites.

Figure 18: GWEN and (e)Loran in CONUS

4.4 Additional Stations – High Latitudes. PNT will become more critical in the Arctic, Antarctic, and Northwest Passage with the increased efforts to locate gas and oil, and to reduce the costs of transporting materials from the Atlantic to the Pacific Oceans. The Arctic region, particularly offshore, has huge oil and gas reserves, mostly in Russia, Canada, Alaska, Greenland and Norway.

A 2004 report commissioned by the United States, Canada, Russia, Denmark, Iceland, Sweden, Norway and Finland concluded that "offshore oil exploration and production are likely to benefit from less extensive and thinner sea ice". Energy companies will find it easier to transport oil and gas because the warmer temperatures might open sea routes. "By the end of this century, the length of the navigation season ... along the Northern Sea route is projected to increase to about 120 days from the current 20-30 days," the report said. However, a longer shipping season will increase the risk of oil spills, the report warned. [19]

In the 1980's, scientists discovered large deposits of natural resources such as coal, natural gas, and offshore oil reserves in Antarctica. Scientists further believe that Antarctica may hold one of the last supergiant oil fields. The Weddell and Ross Sea areas alone are expected to possess 50 billion barrels of oil - an amount roughly equivalent to that of Alaska's estimated reserves. [20]

As seen in figure 19, the Northwest Passage is a famous sea route that links the Atlantic and Pacific Oceans. Until recently, the sea has been frozen over for most of the year preventing its use as a practical alternative, and shorter passage from Europe to Asia. [21]

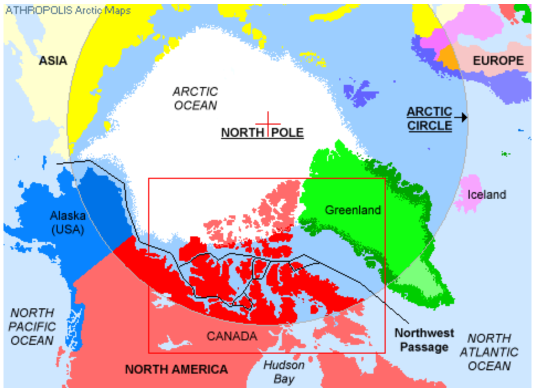

Figure 19: Northwest Passage

Since the summer of 2000, several ships have taken advantage of thinning summer ice cover on the Arctic Ocean to make the crossing. It is thought that global warming is likely to open the passage for increasing periods of time, making it attractive as a major shipping route. [22] Figure 20 shows the Arctic sea ice shrinkage from 1979 to 2007. [23]

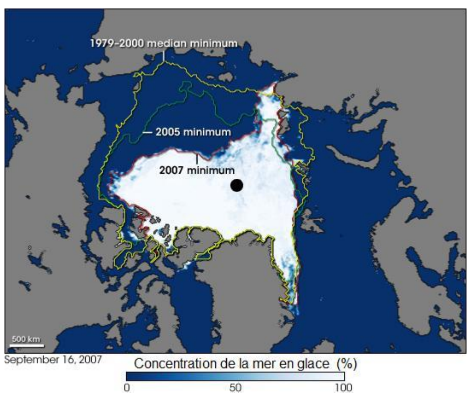

Figure 20: Arctic Sea Ice Shrinkage

The NOAA Space Weather Prediction Center (SWPC) indicates that a key problem with PNT in all three areas of geomagnetic high latitudes – Arctic, Antarctic, and the Northwest Passage – is the hampering of GPS operations when signals from the GPS spacecraft pass through the auroral oval. Figure 21 shows the likely location of the auroral oval, using recent data. Colored areas are most likely to interfere with GPS. The oval moves closer to the equator when geomagnetic activity increases. The NOAA SWPC states that “large quantities of solar energetic particles can also cause scintillation at high latitudes” and if the proton environment is enhanced “conditions may exist that are adverse for GPS users”. [24]

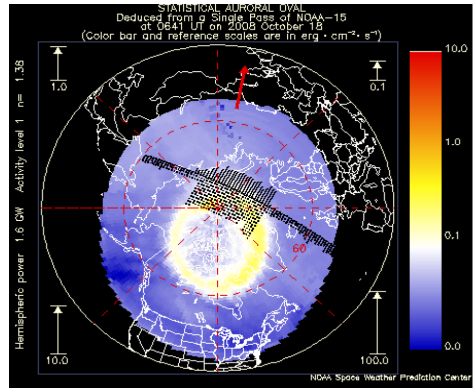

Figure 21: Auroral Oval

Properly positioned (e)Loran stations, using the Next Generation LF transmitters, could provide economical PNT&D coverage in the Arctic, Antarctic, or Northwest Passage, either as temporary or permanent solutions, where GPS signals might be compromised.

4.5 Tracking and Monitoring. The (e)Loran system could be used to track or monitor vehicles, equipment, or individuals in areas where GPS signals might be masked, including urban canyons. According to the U.S. Army, this system would fulfill positioning requirements for “first responders (fire, police and other rescuers), transportation tracking and guidance (trucks and delivery), construction, house arrest prisoners, and Alzheimer patients.” [25]

DARPA’s Strategic Technology Office is seeking alternative Robust Surface Navigation (RSN) solutions when the Global Positioning System (GPS) is unavailable because of hostile action (e.g. jamming or spoofing) or blockage by structures and foliage. In August 2006, Special Operations Technology magazine reported that “No fewer than three agencies within DoD have begun programs to overcome the problem of denied GPS in recent months ...”. [26]. A tactical version of (e)Loran could easily serve as a PNT&D solution in a GPS-denied environment. Historical testing of Loran-C and Loran-D during the Vietnam-era conflicts showed that these LF signals can penetrate triple canopy areas. Fixed or tactical (e)Loran systems, used in conjunction with miniature receivers with data logging capability, could be used to track drug and human traffickers. Additionally, (e)Loran could be used to reduce or eliminate the false alarms common with GPS-based systems for monitoring sex offenders and other convicts. [27]

Several automobile companies provide in-vehicle electronic safety and security systems, also known as automotive telematics systems. For example, OnStar's website describes this General Motors (GM) service as "the in-vehicle safety and security system created to help protect [people] when they are on the road. OnStar's system offers:

- 24-hour access to expertly trained, caring Advisors
- A connection to emergency assistance
- Access to OnStar Hands-Free Calling" [28]

Chet Huber, President of GM OnStar, during a presentation to the NASA PNT Advisory Committee, pointed out that "GPS location & clock are critical enablers for all OnStar services". [29] OnStar currently has over five-million active subscribers, and expects growth estimated at over four-million per year starting in 2008 when it becomes standard in all GM vehicles. OnStar's services include:

- Airbag notification,
- Advanced automatic crash notification,
- Stolen vehicle location assistance,
- Route support,
- Roadside assistance, and
- Targeted Amber alerts.

Lexus Link, Mercedes Teleaid, and BMW Assist are similar services to OnStar. The author is unaware of any backup location or clock service for these providers in the event of a GPS outage. (e)Loran can provide those backup solutions. Cost effective Next Generation (e)Loran transmitters enable long-term, low-cost transmission of PNT&D services to the general public users of telematics services.

4.6 Wide-area or Localized Stratum-1 Timing Sources. In this scenario, (e)Loran would be used to coherentize a network of users who require GPS independence or are operating in an area where GPS reception is marginal. Any (e)Loran site can provide frequency sytonization at the Stratum-1 level and time synchronization at the 100 ns level (assuming differential service). "Professor Sync" states that the impact of a GPS outage could be minimal or nothing IF the user has properly installed backup oscillators that provide holdover capability (cesium, rubidium, or crystal, in decreasing order of holdover capability). [30] However, using the (government) service provided backup timing source readily available as part of the (e)Loran signal is certainly more cost effective.

4.7 Component Solutions. Given the low cost, ease of installation, and small footprint of the conceptual system, it is obvious that it can be disaggregated into its individual components for rapid deployment where needed. We believe a tactical transmitter might be the most necessary component of a Tactical Loran system for North American purposes. For example, a tactical transmitter would be useful under any of the following circumstances:

- Flooding resulting from storm surges either destroying the transmitter, or making it temporarily unusable,
- Fire, earthquake, tornado, or terrorist event destroying the transmitter, and
- Temporary use during changeover from earlier generation transmitters to newer technology.

Note that some legacy transmitters are mid-1970's vintage, and have actually exceeded their original life expectancy. The changeover from Tube-Type Transmitters (TTX) has required construction of new buildings to reduce station "down time". A smaller footprint "temporary" transmitter, such as the Next Generation (e)Loran transmitter could easily operate into the existing antenna during the time it takes to remove the existing transmitter and install the new transmitter. In fact, the "temporary" transmitter could actually become the fully installed transmitter once the legacy transmitter is removed. The savings resulting from not having to construct one new building, especially in Alaska, could easily cover the costs of a Next Generation transmitter.

4.8 System Replacement. TACAN (Tactical Air Navigation) is the military equivalent of VOR/DME. Used in aircraft and on ships, it provides station-referenced bearing and distance functions similar to the civil VHF Omnirange (VOR) and Distance Measuring Equipment (DME). The distance functions are identical for the two systems, but the military's TACAN azimuth signals are theoretically capable of nine times the accuracy of VOR azimuth. (In the real world, this advantage is reported to be more like a two-fold increase in angular accuracy). [31]

There are somewhat more than one hundred CONUS TACAN stations, many combined with VOR azimuth subsystems for dual civil/military use. The Department of Defense (DoD) has some 30 ground-based TACAN stations located on military bases outside the U.S. and about one hundred mobile TACANs. (These could include airborne TACAN units used to assist aircraft positioning during aerial refueling operations - somewhat akin to an instrument-approach function.) [31]

Since the mid-1980s and perhaps earlier, there are references to Loran replacing the VOR azimuth function. Factors for discussion have always included system costs, fleet equipage, and, of course, the "four horsemen": accuracy, availability continuity and integrity. Loran's area-navigation fix geometry (now improved further by *eLoran* architecture) is recognized as potentially superior given the geometric dilution of precision with distance which is inherent in the TACAN (and VOR) azimuth measurements. [31]

Recent discussions with and within the FAA indicate there may be some interest in revisiting replacing TACAN with the combined benefits of GPS and (e)Loran. At this point, there has been no discussion of replacing the distance-measuring subsystems of VOR/DME and TACAN, since the desirable rho-rho position fix is in widespread use by both civil and military users. Loran backup does offer comparative advantages there also, however (cost, low-altitude signal availability and the removal of the active interrogation from the aircraft, reducing the probability of intercept). [31]

It is apparent that the tactical (e)Loran capability enabled by the Next Generation (e)Loran transmitter might make reviving research into replacing the TACAN systems, especially the deployable versions, cost effective.

Other systems that could take advantage of the Next Generation LF transmitter technology are the subsurface/submarine communications community. Although not an (e)Loran service, the transmitter technology is fully applicable to LF signal formats, yielding commensurate SWAIP savings. It might also be of interest to determine whether (e)Loran and submarine communications services could be simultaneously broadcast on the same transmitter from the same facility, thereby producing considerable savings in shared-facility costs.

4.9 System Backup. The General Lighthouse Authorities of the United Kingdom and Ireland (GLAs) recently published a paper discussing the effects of GPS jamming on safe navigation at sea. In the paper, effects on GPS and DGPS receivers, Synchronized Lights, Automatic Identification System (AIS), Electronic Chart Display and Information System (ECDIS), Digital Selective Calling (DSC), communications, ships dynamic positioning system, and ships gyro calibration system, as well as general situational awareness impacts, were discussed. This information is especially critical when Most Efficient Operations (MEO), minimally-manned crews, and the proliferation of safety-of-life systems, such as the U.S. Coast Guard’s Rescue 21, Global Maritime Distress and Safety System (GMDSS), and Nationwide AIS (NAIS), is increasing. All of these systems either depend directly upon, or use location- or timing-based information solely from GPS. Information from these systems then feed other systems, such as Vessel Traffic Service (VTS) and Sector Command Centers (SCC), which are then also affected. Using (e)Loran as a backup effectively precludes catastrophic loss of situational awareness and communications within its service area if GPS is compromised.

5.0 Alternative Tactical Deployment Methods. Tactical (e)Loran refers not only to the ability to rapidly deploy position, navigation, timing, and data capability on the ground, but also to deploy that capability via alternate means, such as aerostats, airships, fixed wing aircraft, and large navigational buoys. As we will see in the following sections, tactical (e)Loran capability could easily be fitted on various moving vessels. Obviously, aerostats, airships, and large navigational buoys provide either continuous or near continuous persistence of transmissions, whereas transmissions from fixed-wing aircraft would be less persistent. Finally, existing infrastructure might be used to provide tactical (e)Loran capability. In one example, reuse of the Ground Wave Emergency Network (GWEN) aerostats might be one viable alternative in North America. In another example, an offshore platform could easily support an (e)Loran site.

5.1 Aerostats and Airships. The Department of Defense has a long history of using airships (often called blimps) and aerostats as platforms to meet various operational and support requirements. Probably the most visible and well-known program today is the Tethered Aerostat Radar System (TARS) that has been operating at eight sites along the southern U.S. border and in the Caribbean since the 1980’s. The TARS primary mission is surveillance for drug interdiction. Each of the TARS aerostats can lift 2,200 pounds of radar or other sensors up to 12,000 feet, and can stay aloft for months at a time. [32]

Both the land based and sea based aerostat make excellent platforms for tactical (e)Loran, especially when using the Next Generation transmitter. The aerostat simply lofts a wire antenna to an appropriate height and the base station or vessel hosts all the required transmitting, timing, and control equipment. Operations could theoretically continue indefinitely in one location, or the entire “site” could be relocated at a moment’s notice.

Figure 22 depicts a representative TCOM, LP land based aerostat moored to a mobile platform. Note that the aerostat would only be necessary when a rapidly deployable, reusable, and relatively cheap antenna is required. Figure 23 depicts a similar configuration using a TCOM, LP sea based aerostat.

Figure 22: TCOM Land Based Aerostat.

Figure 23: TCOM Sea Based Aerostat.

Additionally, airships are capable of inexpensive and fairly rapid deployment of cargo. Tactical (e)Loran capability might be deployed anywhere in the world as an installed package aboard such a vessel, with a trailing wire used as the antenna.

5.2 Fixed Wing Aircraft. Deployment of a high-powered VLF/LF transmitting capability has existed since the early 1960's. In the United States military, the primary means of communicating with submerged submarines is the TACAMO (Take Charge and Move Out) system which uses a fleet of aircraft. The 16 aircraft are part of the World Wide Airborne Command Post (WWABNCP) providing survivable, reliable, and endurable airborne command, control, and communications between the National Command Authority (NCA) and U.S. strategic and non-strategic forces. Two aircraft are always airborne - one over the Atlantic and one over the Pacific. Other aircraft are stationed on the ground and they are on a 15 minute alert. The aircraft fly 10.5 hour missions, starting at one airfield and ending at another. Random patterns are flown to mislead any unauthorized observers. The TACAMO aircraft can receive and relay signals from a number of different ground command posts. Each aircraft is equipped with a 6.2 mile long trailing wire antenna (wound on a reel) and a 100 kW transmitter operating in the VLF region. When the aircraft has to transmit a message, it banks and proceeds to fly a very tight circle. This causes the trailing wire antenna to hang vertically below. Once the message is transmitted over the VLF downlink the aircraft resumes normal flight. [33]

The TACAMO fleet was initially comprised of the Lockheed Hercules EC130 aircraft, but these were gradually phased out and replaced with the Boeing 747 AWACS type aircraft. These aircraft have the capability to transmit a 200 kW signal using a 2.5 mile trailing antenna.

In 1989, the E-6A, and then in 1998, the E-6B aircraft, which is a modified Boeing 707-320B with CFM-56 engines, began fulfilling the role of the TACAMO platform. Figure 24 depicts one such aircraft. It features a very-low-frequency (VLF) dual trailing wire antenna system to permit one-way, emergency communications to submerged submarines. The VLF system includes an onboard power amplifier-coupler connected to two wire antennas, one about five miles long (28,000 feet) and one slightly less than a mile long (5,000 feet). When deployed, the antennas trail behind and below the aircraft. After deployment of the wires, the aircraft banks sharply and flies a circular orbit that allows the longer wire to hang as vertically as possible to enhance signal transmission. [34]

The transmitter on board the TACAMO aircraft is an AN/ART-54 High-Power Transmitting Set (HPTS), consisting of a Solid State Power Amplifier/Coupler (SSPA/C) OG-187/ART-54 and Dual Trailing Wire Antenna System (DTWA) OE-456/ART-54. [35] There is no doubt that the Next Generation Transmitter technology could be applied to the ELF band and, because of its small SWAIP, would improve the TACAMO aircraft's capabilities.

Figure 24: E-6B TACAMO Aircraft.

5.3 Large Navigational Buoys. The National Data Buoy Center's fleet of moored buoys includes several large diameter models. Typically known as Large Navigational Buoys (LNB), these large seaworthy platforms are available in 6-meter, 10-meter, and 12-meter discus hulls. The choice of hull type used usually depends on its intended deployment location and measurement requirements. To assure optimum performance, a specific mooring design is produced based on hull type, location, and water depth. A large discus buoy deployed in the deep ocean may require a combination of chain, nylon, and buoyant polypropylene materials designed for many years of service. Some deep ocean moorings have operated without failure for over 10 years. [36]

Although a buoy is probably not the first choice, it is possible to use a large navigational buoy as a tactical (e)Loran platform, especially when the small SWAIP of the Next Generation transmitter is considered as the core component. The reliability of the system would obviously depend upon the roughness of the water. However, the LNB could be used on inland waterways as well as offshore. Deploying (e)Loran using an LNB would require lofting the antenna with an aerostat. Figure 25 is a 12-meter discus hull LNB being used by the FAA.

Figure 25: Large Navigational "FAA" Buoy

5.4 Offshore Platforms. Offshore platforms have many uses including oil exploration and production, navigation, ship loading and unloading, and to support bridges and causeways. [37] We need only look at the platform shown in figure 12 to get some idea of the usefulness of this type of platform to support an (e)Loran site using the Nest Generation transmitter. With over 3,200 platforms currently installed in the Gulf of Mexico alone, there is a high probability that platforms would be located proximate to an area requiring (e)Loran capability.


Figure 26: Offshore Technologies – Caspian Sea

5.5 Lunar Navigation and Beyond. NASA's Science Mission Directorate, as part of its International Lunar Network partnership, plans to establish science stations on the lunar surface beginning in 2013-2014, followed by human return to the Moon and establishment of the first lunar outpost beginning in 2020. Communications, networking, and navigation capabilities required to support these efforts could be provided by the U.S. Government, other international space agencies participating in the Science and Exploration initiatives, or by private companies. [38] The Next Generation LF transmitter can be appropriately sized to provide initial essential PNT&D services on the lunar surface. Although the long-term solution will invariably be a Lunar Relay Satellite system, it would be more cost effective prior to a human mission to land small, remotely deployable, solar-powered (e)Loran sites that would provide self-contained PNT&D, initially as a primary service and later as a backup/redundant service. (e)Loran was selected as the signal format simply because of its proven effectiveness on Earth. However, the lunar PNT&D signal specification does not need to match that of (e)Loran. Obviously, skywaves and crossrate interference (at least initially) will not be a problem! We can expect signal specifications to be modified to meet lunar requirements. Figure 27 depicts the Lunar Architecture Team's (LAT) Single Habitat Element. It is relatively easy to visualize a low-power LF transceiver site installed in one of the Surface Mobility Carriers (SMC). The SMC could contain a micro-(e)Loran transmitter, driving an inflatable antenna, and powered by a Solar Power Unit. This system could easily synchronize with any Lunar Relay Satellite system deployed around the Moon in future missions, and through that link, synchronize with GNSS orbiting the Earth. Once tested on the Moon, the system is extensible to Mars mission efforts.

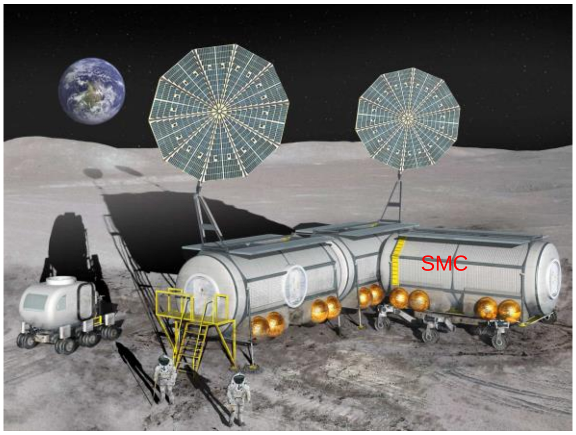

Figure 27: NASA's LAT Single Habitat Element

6.0 Impact of the Next Generation LF Transmitter. Increasingly, service providers are asking themselves: "How do I do more with what I have?" and "What do I do with my installed base?" My advice it to look at legacy systems in terms of:

- Functional health: Is the system doing what it's supposed to do?
- Technical health: Is the system healthy?
- Financial health: What is the system costing? [39]

6.1 Functional Health. In the case of the U.S. Loran system, there is no doubt it is doing what it was designed to do: "supporting PNT service for air, land, and marine users". [40] However, some of the installed technology is dated and therefore its full operational capability has not been tapped. With the advent of eLoran, and various modernization and recapitalization efforts, the system can also do what it's supposed to do – even though the mission is somewhat new: be "an independent national positioning, navigation and timing system that complements the Global Positioning System (GPS) in the event of an outage or disruption in service". [5]

6.2 Technical Health. As to the technical health of the system, it is apparent that service providers are finding it difficult to fund primary PNT systems, let alone backup systems, at their full technical health. According to the U.S. Air Force, as of September 2008 there were 19 Space Vehicles (SVs) past their design life, 15 SVs past their pre-launch mean life estimate, 18 SVs one component away from navigation mission failure, and eight (8) SVs one component away from bus failure. [41] There is a need to address the technical health of the primary system – GPS – but the situation also points to the need to address the health of the backup system. Now let us focus on the technical health of the U.S. Loran system. First, there remain several third generation TTX stations in operation. This technology has gone "end-of-life" and the people are being lost who understand it. Not only is the Loran generation technology obsolete, but the infrastructure enclosing that technology is in need of recapitalization. Next, there are fourth generation SSX stations in operation that are approaching or beyond the end of their design life. Finally, the eLoran technology has not been fully implemented in the U.S.

6.3 Financial Health. When considering the financial health of the U.S. Loran system, there are really several cost issues. It is far cheaper and faster to bring the backup system up to full operational capability for years into the future than it is to build and launch a single replacement GPS satellite. Note that the author does not suggest slowing down continuous improvements to the GPS constellation. In the U.S. case, it is also cheaper to complete upgrading the Loran system to eLoran than to face the prospect of a GPS outage with insufficient backup capability in place. Using newer Next Generation LF Transmitter technology reduces the costs to the point where both systems can be improved simultaneously with only a slight incremental cost, when compared to the overall annual cost of the GPS.

6.4 Modernization Costs. Although approximately $160M has been spent to modernize and upgrade the U.S. Loran system, the work is not complete. Faced with estimates as high as $400M to complete the modernization effort and transition to eLoran [42], it is apparent that a game-changing innovation is required to reduce the costs to the point where full implementation is manageable. The Next Generation (e)Loran transmitter provides that game-changing technology.

With the Next Generation (e)Loran transmitter as the core, it is easier to fund renewing the system. We can take cost out of the system by applying the new, cost effective technology. We can reduce the risk of continuing to operate legacy equipment that is increasingly costly to operate and maintain. We can increase the agility of the system by installing technology that is capable of delivering today's enhancements, but that also includes some level of future-proofing: the ability and agility to provide tomorrow's enhancements as well.

6.5 Taking cost out of the system. (e)Loran facility costs can generally be broken down into several components: physical infrastructure (e.g., buildings, HVAC, power generation), antenna, transmitter, signal generation, ancillary equipment, and any requisite administrative, maintenance, logistics, and personnel support spaces (e.g., barracks, galley, runway, motor pool, etc.). Some of these costs were a result of remote locations and/or full-time personnel requirements. Many of these costs can be reduced or eliminated if the (e)Loran facility is envisioned as a *site* versus a *station*. That is, if the intention is for the site to simply provide a signal in space (similar to DGPS, telecommunications, AM, FM, television, and VTS radar sites), rather than be a workplace destination, then it is on the order of 75 percent less expensive. An (e)Loran site could be as simple as an ELB and associated transmit and receive antennas. For example, instead of constructing an $8M building, such as was rumored at LORSTA St. Paul, AK, a $200K ELB enclosure is all that is required. If there is no requirement for a MIL-SPEC enclosure, then the cost is reduced even further.

Another cost saving possibility, when using the Next Generation (e)Loran transmitter, is installing the equipment in an existing structure alongside or near the existing transmitter. This type of “side-by-side” installation is extremely cost effective, and has been performed with much larger and more complex transmitters at LORSTAs Baudette, MN and Caribou, ME.

An ELB solution is a study in rapid-prototyping and development. Once a short site survey is completed, the resulting equipment suite design can either be installed and shipped within the enclosure or packaged and shipped separately. When outfitted within a standard ISO container, complete (e)Loran sites can be transported using military or commercial rail, truck, ship, or aircraft.

An ELB implementation provides for almost immediate unattended operations, even at difficult, remotely located sites. For example, the gold-standard of isolation and hardship has typically been LORSTA Attu Island, Alaska. Installing an ELB either within the 1990’s vintage transmitter building (or on its rooftop, weight permitting) might preclude having to relocate the facility. An optimal solution might include a “double-double” NL Series transmitter; that is, two fully redundant transmitters with near-100% availability installed in a single ISO 40-foot or two ISO 20-foot enclosures. Once the new site is installed, helicopter provisioning could be accomplished over the approximate 40-mile distance between Shemya and Attu. There would no longer be a need for U.S. Coast Guard C-130 logistics flights to support (e)Loran operations.

An NL Series transmitter-based (e)Loran solution would typically take days to install vice weeks, with a couple of technical personnel vice a team. Once pre-site work is completed, an ELB-based installation, testing, and certification is expected to take approximately three days.

To recap, the savings begin to add up quickly:

- economical NL Series Transmitter,
- short manufacturing time,
- less installation time and personnel,
- less equipment shipping and storage cost,
- no specialized installation tools or hardware,
- less travel and per diem,
- no need for new building construction,
- limited, or no, HVAC requirements,
- lower input power requirement,
- reduced logistics tail,
- reduced training costs,
- reduced maintenance costs, and
- ability to minimally man or unman sites.

6.6 Reducing Risk. To reduce the risk associated with operating obsolete or legacy equipment, it is imperative to quickly and economically replace those systems with the most modern and advanced technology available. Whether it is replatforming, remediating, consolidating, replacing, or enhancing the legacy technology, it cannot be accomplished if the perceived costs are higher than the perceived risks. Using the Next Generation (e)Loran transmitter will allow us to reduce the risks at a much lower cost.

In cases where Service Life Extension Programs (SLEP) are being considered to prolong the serviceable life of legacy systems, it may be more economical to completely replace the legacy system than to refurbish it. This approach injects the latest technology into the system at a cost that is commensurate with simply replacing the worn-out components in old technology with new ones.

6.7 Increasing Agility. When we continue to use older technology, we are not optimizing availability, accuracy, integrity, and continuity. [43] For (e)Loran to be the best possible backup to GPS, we should make every effort to reduce the error budget associated with signal generation and reception. We have no control over the atmosphere or propagation path effects, but we can ensure the transmitted signal is as stable as possible. The Next Generation (e)Loran transmitter technology is inherently adaptable and agile, providing superior pulse time, frequency, and shape control. Because the pulses are software generated “on-the-fly”, and feedback is monitored in real time, minor imperfections can be corrected in near real time. Additionally, while no current need exists, the transmitter has demonstrated the ability to produce 600 PPS and higher, and is capable of operation using advanced modulation schemes.

7. Summary or Conclusions

We have discussed how new technology can be applied to reduce the costs of operating and maintaining PNT&D systems. The Next Generation LF Transmitter technology, whether applied to Loran, eLoran, Tactical Loran, or other LF systems, provides high performance, has some measure of future-proofing, and is economical to buy, install, operate, and maintain.

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* **LORAN** is an acronym for **LO**ng **RA**nge **N**avigation, but is often spelled **Loran**.