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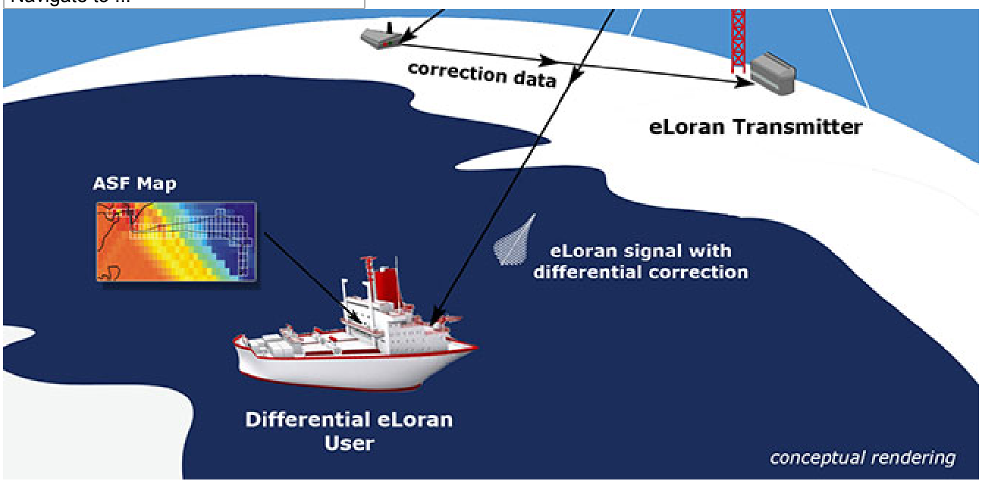

Innovation: Enhanced Loran

November 23, 2015 - By GPS World staff

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A Wide-Area Multi-Application PNT Resiliency Solution

By Stephen Bartlett, Gerard Offermans and Charles Schue

INNOVATION INSIGHTS with Richard Langley

WHERE HAVE ALL THE SYSTEMS GONE, long time passing?

Radionavigation systems, that is (and apologies to Pete Seeger). If we look at the 1990 Federal Radionavigation Plan (FRP), published by the U.S. Departments of Transportation and Defense, as I did in this column in March 1992, we see that there were 10 radionavigation systems in use by different user segments: Loran-C, Omega, very high frequency (VHF) Omnidirectional Range/Distance Measuring Equipment, Tactical Air Navigation, the Instrument Landing System, the Microwave Landing System, Transit, aviation radiobeacons, marine radiobeacons and GPS.

The latest FRP, issued in 2014, includes only seven or six and a half when you consider that marine radiobeacons were mostly phased out in the intervening years. Systems were shut down because with the advent of GPS, they were considered to be redundant. While there were attendant cost savings, the closure of the various systems has resulted in a dangerous virtual sole dependence on GPS for navigation without any backup.

Transit, was the first to go. It consisted of a constellation of six or seven active satellites in circular, polar orbits at altitudes of roughly 1,100 kilometers. The satellites transmitted signals on 150 and 400 MHz, and receivers measured the integrated Doppler frequency shift of the received signals. Transit was terminated at the end of 1996.

Transit was followed by the Omega hyperbolic navigation system. Omega consisted of eight stations around the globe transmitting time-shared carrier-wave signals on four frequencies between 10.2 and 13.6 kHz. The Omega system was closed down in September 1997.

The marine radiobeacons have been mostly shut down in recent years, although aeronautical beacons continue to operate. Radiobeacons are nondirectional transmitters that operate in the low- and medium-frequency bands. Some marine radiobeacons became Differential GPS stations and subsequently part of the Nationwide DGPS network. That network is being scaled back to provide only coastal and Great Lakes coverage.

And that brings us to Loran-C. Like Omega, it was also a hyperbolic navigation system. A receiver measured the difference in times of arrival of pulses transmitted at 100 kHz by a chain of three to five synchronized stations separated by hundreds of kilometers. At one time, the operation of Loran-C was the responsibility of the U.S. Coast Guard. Together with a number of host nations, the Coast Guard operated 17 chains of stations around the world, including one jointly operated with Russia. These stations provided coverage of the coastal areas of North America and the U.S. interior, northern Europe, the Mediterranean Sea, the Far East and the Hawaiian Islands. Additionally, several other countries operated Loran-C stations. Although moves were already underway to update the Loran technology, the Obama administration decided to terminate Loran-C in the U.S., considering it to be an unnecessary antiquated system. The Coast Guard terminated the transmission of all U.S. Loran-C signals in February 2010 and began dismantling stations.

So, is there no longer a viable non-GNSS alternative or backup system for GPS navigation? While there are other possibilities for time transfer, one of GPS's other applications, there is no widely available substitute navigation system. Currently. However, as we will see in this month's column, a new version of Loran — Enhanced Loran or eLoran — has been developed and is being tested on the U.S. east coast. Not your father's Loran, eLoran seems to be the perfect solution for PNT resiliency.

Telecommunications, energy, finance and transportation are just four among the many critical infrastructure / key resource sectors that have come to rely solely on GPS for positioning, navigation and timing (PNT). In fact, the U.S. Department of Homeland Security (DHS) has determined that 11 of the 16 critical infrastructure sectors in the U.S. are critically dependent on GPS for timing. While we can start to imagine what a day without GPS might be like, we'd really rather not — it would be somewhat depressing and really quite dangerous. We would rather imagine a day when there is a wide-area complementary solution available that protects and augments GPS. In this article, we will delve into such a solution: Enhanced Loran, or eLoran for short. We will explain how it works, debunk some myths, speculate on how it could be used in the U.S. (and abroad), highlight the state of current technology and discuss the state of the possible. We will also summarize the state of eLoran in the world and where things might go from here.

What Is eLoran?

eLoran is the latest in the longstanding and proven series of low-frequency, LOng-RAnge Navigation (LORAN) systems, one that takes full advantage of 21st-century technology. It meets the accuracy, availability, integrity and continuity performance requirements for maritime harbor entrance and approach maneuvers, aviation non-precision instrument approaches, land-mobile vehicle navigation and location-based services. It's a precise source of time (phase) and frequency. Additionally, eLoran provides user bearing (azimuth) and has built-in integrity. In full disclosure, however, eLoran is only a 2D positioning solution unless integrated with a simple altimeter.

eLoran is a low-frequency radionavigation system that operates in the frequency band of 90 to 110 kHz. eLoran is built on internationally standardized Loran-C, and provides a high-power PNT service for use by all modes of transport and in other applications. eLoran is an independent dissimilar complement to GNSS. It allows GNSS users to retain the safety, security and economic benefits of GNSS even when their satellite services are disrupted.

eLoran uses pulsed signals at a center frequency of 100 kHz. The pulses are designed to allow receivers to distinguish between the groundwave and skywave components in the received composite signal. This way, the eLoran signals can be used over very long ranges without fading or uncertainty in the time-of-arrival (TOA) measurement related to skywaves.

Although eLoran is based upon Loran-C, it has key differences:

- All transmissions are synchronized to UTC (like GPS)
- Time-of-transmission control
- The ability to use differential corrections (similar to DGPS)
- Receivers use “all-in-view” signals
- Includes one or more Loran data channels that provide: Low-rate data messaging, added integrity, differential corrections (dLoran and/or DGPS) and other communications including navigation messages.

An eLoran receiver measures the TOA of the eLoran signal:

$TOA = TOR – TOT = PF + SF + ASF + \Delta Rx$

where *TOR* is time of reception, *TOT* is time of transmission, *PF* is the primary factor (propagation delay through air), *SF* is the secondary factor (propagation delay over sea), *ASF* is the additional secondary factor (propagation delay over terrain) and ΔRx is the delay due to receiver electronics and cables.

The primary and secondary factors are well-defined delays and can be calculated as a function of distance. The additional secondary factor delay is mostly unknown at the time of installation. Fortunately, the ASFs remain very stable over time. Any fine changes in ASF over time may be compensated for by one or more differential eLoran reference station sites providing corrections over the Loran data channel.

When eLoran is used for positioning, a minimum of three eLoran transmitting sites are needed to calculate a two-dimensional position fix and time. Time (phase) and frequency can be derived from a single transmitting site as well. With three sites, timing can be derived while a receiver is in motion. An integrated eLoran/GPS receiver can take advantage of combinations of eLoran and GPS transmissions to develop a PNT solution. Any additional measurements provide a means to improve the solution’s accuracy (using weighted least squares) or to protect the solution’s integrity (by receiver-autonomous integrity monitoring).

To achieve the highest accuracy levels, the user receiver corrects its TOA measurements with the published ASF values for the area and differential eLoran corrections received through the Loran data channel. ASF maps for specific geographic areas are distributed to users in a receiver-independent data format that is currently being standardized by the Radio Technical Committee for Maritime Services’ (RTCM’s) Special Committee (SC) 127 on eLoran. The ASF map data would be published by the service provider responsible for aids to navigation.

As described before, the measured ASF values remain stable over long periods of time. Any small changes in the published ASFs due to changes in propagation path characteristics or transmitter-related delays will be compensated for by differential corrections. For this, a differential eLoran reference station site is deployed within 20 to 30 miles (32 to 48 kilometers) of the area of interest. The reference station compares its measured ASFs against the published values and broadcasts corrections to the users through the Loran data channel. Figure 1 shows the principle of differential eLoran positioning in a maritime environment and is representative of its use in other modalities as well.

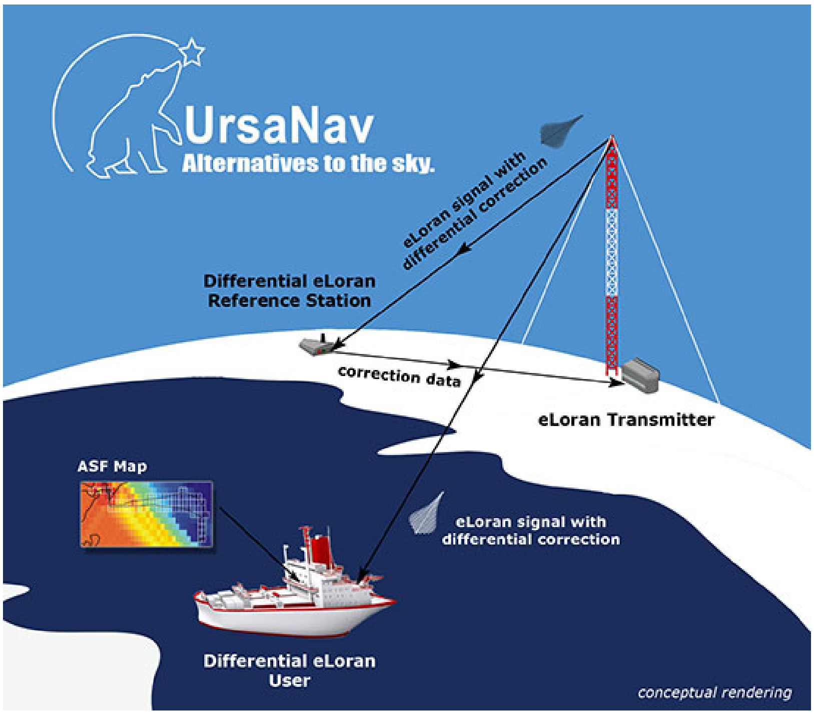


Figure 1. Overview of a representative eLoran system.

eLoran meets the application requirements shown in Table 1. While unaided, Loran-C does not meet the requirements for a multi-modal, redundant PNT system, specifically the position accuracy requirement. The U.S. first developed eLoran to reduce the positioning error and to enable the system to meet modal performance requirements.

Application	Accuracy	Availability	Integrity	Continuity
Maritime harbor entrance and approach	20 meters (95%)	0.998 over two years	10 seconds time to alarm	0.9997 over three hours
Aviation non-precision approach (required navigation performance 0.3)	0.3 nautical mile or 556 meters (95%)	0.999 – 0.9999	1×10^{-7} per hour	0.999 – 0.9999 over 150 seconds
Timing	Stratum-1 frequency stability; timing to ±50 nanoseconds from UTC			

Table 1. eLoran system performance requirements.

eLoran Applications

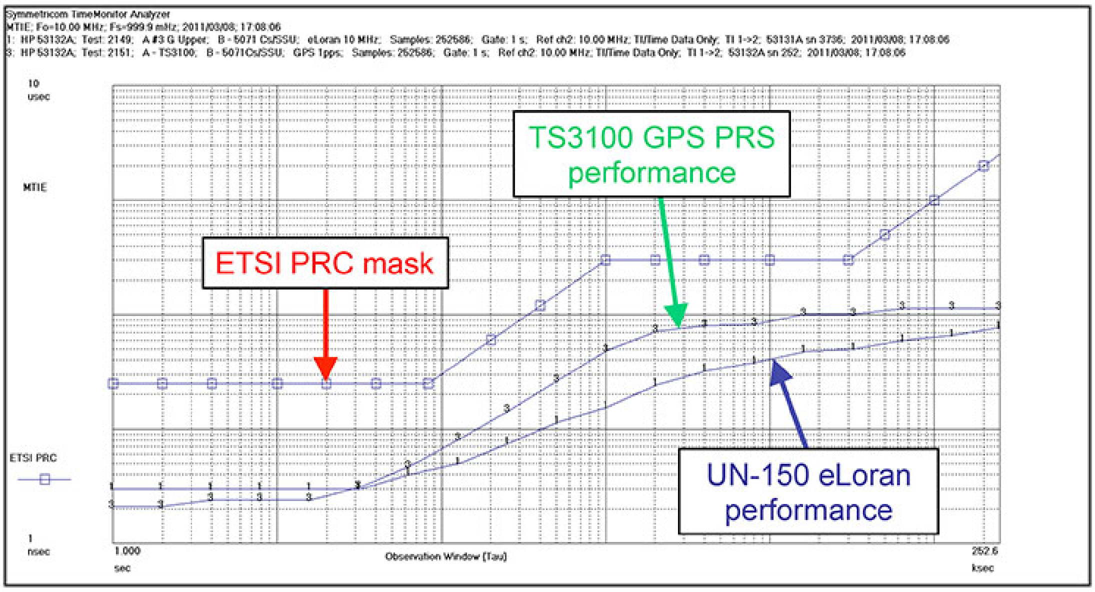
We are staunch advocates of GPS and believe it should be fully funded, kept technically advanced, protected, toughened and augmented. When GPS is available and trustworthy, it should be used. However, no technology is failsafe, and prudent users should not rely on a sole source for their PNT needs. GPS has been called “a single point of failure” for much of the U.S. economy and critical infrastructure. Applications and requirements vary widely from wireless network communications of ± 1.5 microseconds, to maritime harbor entrance and approach requirements of ± 20 meters, to phasor measurement unit requirements in the electric power grid of ± 500 nanoseconds.

It is important to recognize the challenge of providing assured PNT while also taking advantage of the efficiencies gained by implementing a common solution across all sectors, industries and users. Point solutions can provide complementary PNT for specific individual or modal needs, and any resilient PNT ecosystem includes multiple levels of redundancy.

Some key application areas in which eLoran can provide complementary PNT are telecommunications, energy, finance and transportation. We believe these will be some of the first sectors to adopt and exploit eLoran as a component of their critical infrastructure protection and possibly as a co-primary PNT solution alongside GPS.

Telecommunications Sector. A March 2014 letter from the Alliance for Telecommunications Industry Solutions (ATIS) to the National Security Telecommunications Advisory Committee contained an attached document, *Recommended Updates to Telecom Vulnerability to Loss of GPS Signals Documentation,* that outlined three areas of concern that ATIS has identified relating to the exposure of commercial communications systems to a loss of the GPS signal. Included in the documentation was the statement: “With the Loran systems decommissioned, GPS is currently the only technology that can meet synchronization requirements for E911 as there is no other widely available access to UTC time of day in the United States.” eLoran’s Loran data channel provides the UTC time-of-day information that the telecommunications industry seeks, as well as providing complementary timing (phase) and/or frequency solutions that would mitigate ATIS’s concerns about: (1) the size of the area and duration effects of a GPS outage, (2) the effects of spoofing, (3) the inability of oven-controlled crystal oscillators (OCXOs) to maintain phase alignment for 24 hours at 1.5 microseconds, and (4) the phase performance of OCXOs in varying temperature environments.

The European Telecommunications Standards Institute Primary Reference Clock mask is one tool used by the telecommunications industry to determine the quality of timing signals in telecommunication applications. Figure 2 shows that eLoran is able to meet maximum time interval error (a measurement of wander or time stability) requirements, often outperforming GPS. Testing was performed independently in a cooperative effort between the United Kingdom National Physical Laboratory and Chronos Technology Ltd., UrsaNav’s reseller in England.



•Figure 2. Maximum time interval error plot of eLoran and GPS.

Energy Sector. At present, GPS is the only time source for phasor measurement unit (PMU) (also known as synchrophasor) and frequency data recorder (FDR) sensors used to collect data that measures the state of an electrical system and manages power quality. PMUs/FDRs are a necessary component of the movement to a smart-grid approach to improve energy efficiency on the electrical grid and in businesses and homes. PMUs and FDRs cease to work if the GPS signal is lost or unstable. In 2013, UrsaNav began working with the University of Tennessee at Knoxville (UTK) to demonstrate the capability of eLoran, alongside GPS, to provide the necessary timing accuracy for UTK’s high-precision FDRs to collect synchrophasor data from the U.S. power grid. The required accuracy of the timing reference source is ± 500 nanoseconds, needed by each device performing synchrophasor measurements.

The laboratory setup in Bedford, Mass., used side-by-side FDRs: one using a GPS receiver and one using an eLoran receiver. Other than replacing the GPS receiver with an eLoran receiver in one of the FDRs, no other changes were made. The eLoran signals were being transmitted from a former U.S. Coast Guard (USCG) Loran Support Unit in Wildwood, N.J., more than 300 miles (483 kilometers) from our Bedford laboratory.

"Raw" eLoran was used for the test, that is, with no differential corrections nor continuous receiver antenna calibration. Figure 3 shows the resultant frequency and phase angle comparisons between GPS and eLoran. Green is eLoran; black is GPS. Frequency comparisons are on the left, top and bottom. Phase angle comparisons are on the right, top and bottom. The bottom left graph is a blow-up of the area encircled in red in the top left graph. The bottom right graph is a blow-up of the area encircled in red in the top right graph. In both cases, eLoran performs on par with GPS.

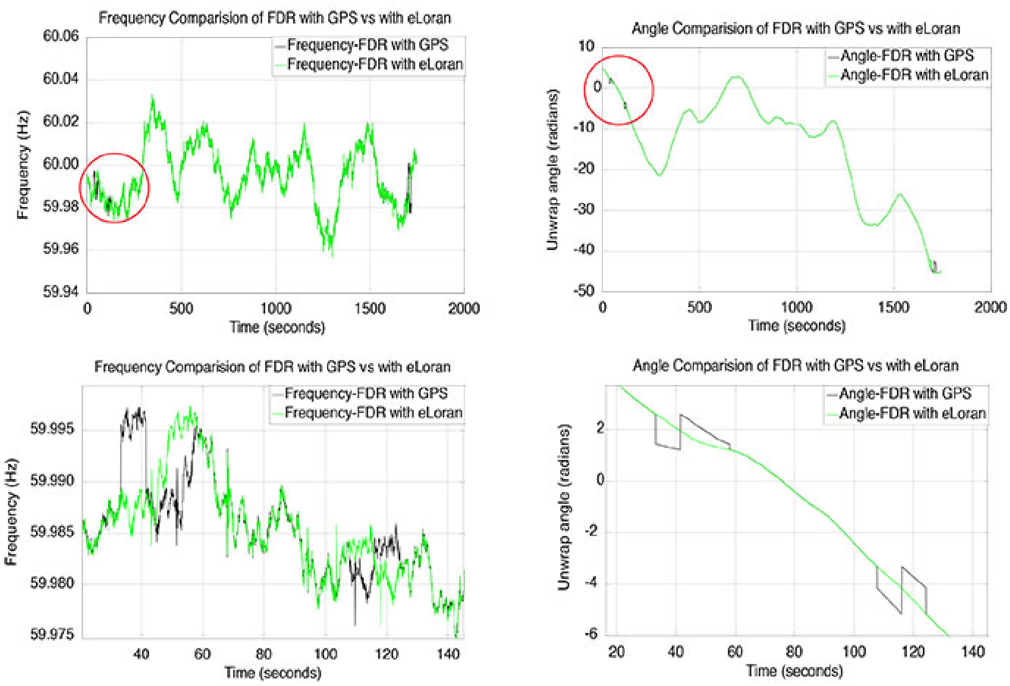


Figure 3. Frequency data recorder outputs from GPS and eLoran.

Financial Sector. A European Securities and Markets Authority (ESMA) report, dated May 22, 2014, indicates that the majority of trading venues are already coordinated with GPS time, and further states that the deployment of these systems might be costly and technically challenging. ESMA's view is that each trading venue and market participant should rely on an atomic clock to issue timestamps. An eLoran timing alternative would be less costly, less technically challenging, and, when used in concert with other solutions (such as GPS, atomic clocks or Network Time Protocol / Precision Time Protocol) would also provide trusted time. eLoran would provide absolute time over very wide areas, thereby allowing dispersed markets and users to take advantage of this synchronized time solution. Additionally, eLoran can often provide time indoors, using a magnetic field (H-field) antenna, thereby precluding the permits and expense required for a rooftop antenna installation. ESMA has asked for industry comment on its proposed requirement to synchronize clocks to the microsecond level, and invited industry responses to its preliminary view that business clocks be accurate at least up to the microsecond level.

Transportation Sector – Aviation. PNT use in air traffic management is illustrative. In accord with U.S. Federal Aviation Administration (FAA) planning, a principal surveillance source in the U.S. national air space (NAS) by 2020 will be Automatic Dependent Surveillance-Broadcast (ADS-B), where the required positional accuracy of aircraft relies on GPS position. Moreover, the independent validation and backup of GPS-derived positions relies on accurate time-of-arrival measurements at a network of 650 radio stations in the NAS that currently use GPS-disciplined clocks with accuracy down to 30 nanoseconds. These radio stations are critical infrastructure of the Surveillance and Broadcast Services (SBS) system, which provides ADS-B surveillance to FAA air traffic management (ATM).

The FAA recognizes the need for a backup to surveillance and navigation in the event of local, regional and wide-scale GPS outages, and is examining both near-term and long-term strategies for continuity of operations during those outages. Because of the long lead times for ATM technology insertion, near-term mitigation strategies out to at least 10 years are constrained by existing ATM ground infrastructure and current avionics capabilities. Long-term solutions are not so constrained, and may be based on new signals in space, new ground infrastructure and new avionics capabilities.

Surveillance. Beginning in 2020, ADS-B will be a principal surveillance technology. In recognition of the need for a backup if GPS fails, the FAA is planning to maintain a mix of beacon-interrogation radar and wide-area multilateration (WAM) in the near term. The long-term strategy is still very much in the evolutionary stage.

Navigation. Near-term strategies involve a mix of approaches based upon existing infrastructure and the current capability of avionics. A leading approach, referred to as DME/DME/IRU, uses two-way ranging to multiple Distance Measuring Equipment (DME) facilities augmented by the avionics inertial reference unit (IRU). This approach is practical and applicable more to air carrier aircraft than regional jets or general aviation. Other approaches rely to some extent on the use of very high frequency Omni-Directional Range (VOR) facilities. As with surveillance, the long-term strategy is very much evolutionary.

It is instructive to note that near-term solutions rely on existing radar, DME and VOR infrastructure because it is in place and is compatible with existing avionics. In the long-term view, new technologies with less costly infrastructure are likely to be more cost-effective, especially if they provide benefits beyond ATM applications. eLoran is such a technology.

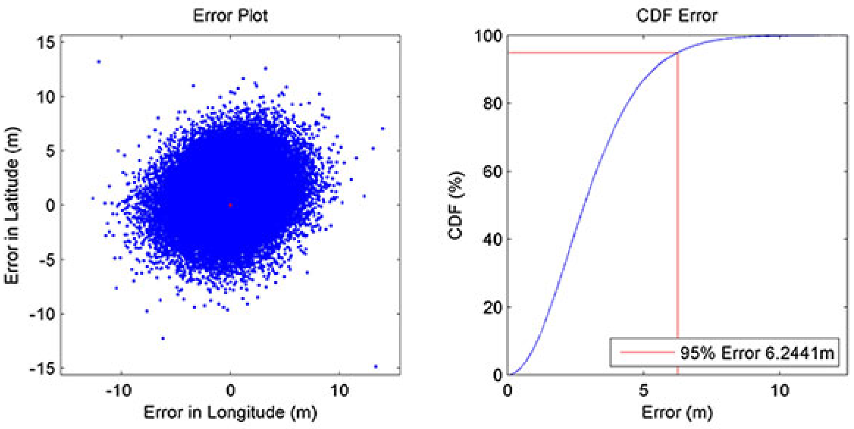
Transportation Sector – Maritime. There is an increasing awareness in the maritime world that no single system can provide PNT resiliently under all circumstances. At this moment, GPS (with augmentations) is used on most commercial vessels, and in many cases integrated into systems we did not expect would need or use GPS-derived position or time. Even though the introduction of GLONASS, Galileo, BeiDou and other GNSS systems will provide some resilience, the underlying (satellite) technology remains the same, only providing relatively weak signals from space at mostly the same or close-by frequencies for compatibility and inter-operability.

The International Maritime Organization (IMO) recognizes the need for multiple PNT systems on board maritime vessels. The organization developed the e-Navigation concept to increase maritime safety and security via means of electronic navigation, which calls for at least two independent dissimilar sources of positioning and time in a navigation system to make it robust and fail safe. As a follow on, IMO's Navigation, Communications and Search and Rescue Committee is considering performance standards for multi-system shipborne navigation receivers, which includes placeholders for satellite, augmentation and terrestrial systems.

The most viable terrestrial system providing PNT services that meet IMO's requirements is eLoran. With three eLoran transmitters in good geometry, eLoran can provide sub-10 meter (95 percent probability level) horizontal positioning accuracy and UTC synchronization within 50 nanoseconds, sufficient to be the co-primary PNT solution with GNSS. The General Lighthouse Authorities of the United Kingdom and Ireland (GLAs) have installed UrsaNav's differential eLoran reference stations to provide the world's first initial operational capability (IOC) eLoran system.

Together with Loran transmitters in England, France, Germany, Norway and Denmark, the differential eLoran reference stations provide better than 10-meter positioning accuracy at seven ports and port approaches along the English and Scottish east coast. IOC was achieved at the end of 2014, with full operational capability planned for 2018. Other nations have either begun, or are exploring, similar projects.

Figure 4 shows the accuracy of an eLoran position at the differential reference station on the Humber River in England. Figure 5 shows the position accuracy while on board a vessel transiting outbound on the river from Humber to the North Sea.



•Figure 4. Zero-baseline accuracy at Humber reference station.

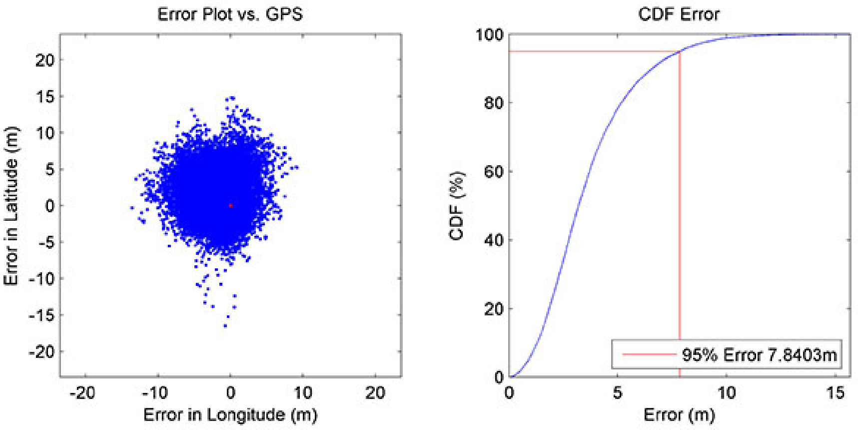


Figure 5. Onboard, en route accuracy on the Humber River.

Current State of eLoran Technology

eLoran technology has been available since the mid-1990s and is still available today. In fact, the state-of-the-art of eLoran continues to advance along with other 21st-century technology. eLoran system technology can be broken down into a few simple components: transmitting site, control and monitor site, differential reference station site and user equipment.

Modern transmitting site equipment consists of a high-power, modular, fully redundant, hot-swappable and software configurable transmitter, and sophisticated timing and control equipment. Standard transmitter configurations are available in power ranges from 125 kilowatts to 1.5 megawatts. The timing and control equipment includes a variety of external timing inputs to a remote time scale, and a local time scale consisting of three ensembled cesium-based primary reference standards. The local time scale is not directly coupled to the remote time scale. Having a robust local time scale while still monitoring many types of external time sources provides a unique ability to provide proof-of-position and proof-of-time. Modern eLoran transmitting site equipment is smaller, lighter, requires less input power, and generates significantly less waste heat than previously used Loran-C equipment.

The core technology at a differential eLoran reference station site consists of three differential eLoran reference station or integrity monitors (RSIMs) configurable as reference station (RS) or integrity monitor (IM) or hot standby (RS or IM). The site includes electric field (E-field) antennas for each of the three RSIMs.

Modern eLoran receivers are really software-defined radios, and are backward compatible with Loran-C and forward compatible, through firmware or software changes. ASF tables are included in the receivers, and can be updated via the Loran data channel. eLoran receivers can be standalone or integrated with GNSS, inertial navigation systems, chip-scale atomic clocks, barometric altimeters, sensors for signals-of-opportunity, and so on. Basically, any technology that can be integrated with GPS can also be integrated with eLoran.

Figure 6 shows a resilient PNT receiver that includes GPS, DGPS, eLoran and a dual-band (100/300 kHz) E-field antenna. The left-hand antenna, shown installed on the P&O Ferries' Pride of Hull, is the resilient PNT antenna. The right-hand antenna is a standard GPS antenna.

•Figure 6. Resilient PNT receiver and dual-band antenna.

World View of eLoran

Nine nations are operating Loran-C or eLoran stations, including Russia and China. It is our understanding that the Republic of Korea, India and the Kingdom of Saudi Arabia are pursuing the installation of eLoran technology or upgrading their Loran-C technology to eLoran.

The modernization and upgrade of the U.S. Loran-C system to eLoran was a congressionally mandated program jointly executed by the FAA and USCG from 1997 to 2009, and funded at $160 million. During this time, eLoran was successfully tested and demonstrated in all modes: aviation, maritime, land-mobile, location-based, and timing and frequency. Further, eLoran has been successfully in operation in the U.K. for several years. Every national and international government, industry and academic report has concluded that GNSS is vulnerable and that eLoran is the best complementary solution to help negate those vulnerabilities.

The U.S. terminated its Loran-C service, and thereby its nascent eLoran program, in 2010. Canada followed suit and terminated its Loran-C service as well. Shortly thereafter, DHS/USCG began dismantling or demolishing the modernized infrastructure. However, in December 2014, Congress directed that DHS/USCG preserve the existing, unused U.S. Loran-C infrastructure, unless the Secretary of Homeland Security certifies it is not needed for a system to complement GPS.

In March 2015, U.S. House of Representatives Resolution (H.R.) 1678, a bill that would require establishment of a strong, difficult-to-disrupt terrestrial system to complement GPS, and to serve as another source of PNT when GPS isn't available, was referred to the Committee on Armed Services. The bill seeks to amend the language that provided for the establishment and management of GPS in Title 10, the section of law that deals with the armed services. We understand that other members of Congress have expressed interest and will be co-sponsoring the bipartisan bill. H.R. 1678 was introduced by Congressman John Garamendi (Democrat, Calif.) with Congressman Duncan Hunter (Republican, Calif.), Congressman Frank LoBiondo (Republican, N.J.) and Congressman Peter DeFazio (Democrat, Ore.) as the initial co-sponsors. In August, the bill was referred to the Subcommittee on Strategic Forces.

Additionally, in May 2015, the DHS and USCG entered into a cooperative research and development agreement with UrsaNav and Exelis (now part of Harris Corp.) to research, evaluate and document at least one alternative to GPS as a means of providing PNT information in the form of eLoran.

It is our understanding that the U.S. Congress is still considerably concerned about the lack of a complementary PNT solution to safeguard U.S. critical infrastructure and key resource sectors, and to protect our economy in the event of a GPS outage. Congress continues to press the administration for a resolution, in the form of a continental U.S. eLoran system, before our nation is placed at further risk.

Acknowledgments

The authors wish to acknowledge the assistance of Dr. Ron Bruno, Harris Corp., and Dr. Paul Williams and Chris Hargreaves, GLAs.

Manufacturers

UrsaNav provided the eLoran receiver and Symmetricom, now Microsemi, provided the GPS receiver for the timing tests shown in Figure 2.

STEVE BARTLETT is vice president of operations at UrsaNav, Inc., North Billerica, Mass.

GERARD OFFERMANS is senior research scientist at UrsaNav engaged in various R&D project work and product development.

CHARLES SCHUE is co-owner and president of UrsaNav.

FURTHER READING

- **eLoran**

"Can eLoran Deliver Resilient PNT?" by N. Ward, C. Hargreaves, P. Williams and M. Bransby in *Proceedings of The Institute of Navigation 2015 Pacific PNT Meeting*, Honolulu, Hawaii, April 20–23, 2015, pp. 1051–1054.

"eLoran Initial Operational Capability in the United Kingdom – First Results" by G. Offermans, E. Johannessen, S. Bartlett, C. Schue, A. Grebnev, M. Bransby, P. Williams and C. Hargreaves in *Proceedings of the 2015 International Technical Meeting of The Institute of Navigation*, Dana Point, Calif., January 26–28, 2015, pp. 27–39.

"Implementing a Wide Area High Accuracy UTC Service via eLoran" by G. Offermans, E. Johannessen and C. Schue in *Proceedings of the 46th Annual Precise Time and Time Interval Systems and Applications Meeting*, Boston, Mass., December 2014, pp. 124–133.

- **Loran-C**

"GPS + LORAN-C: Performance Analysis of an Integrated Tracking System" by J. Carroll in *GPS World*, Vol. 17, No. 7, July 2006, pp. 40–47.

- **Alliance for Telecommunications Industry Solutions**

Letter to National Security Telecommunications Advisory Committee dated March 11, 2014, with attached document, *Recommended Updates to Telecom Vulnerability to Loss of GPS Signals Documentation*.

- **European Telecommunications Standards Institute**

Transmission and Multiplexing (TM); Generic Requirements for Synchronization Networks, EN 300 462-1-1, European Telecommunications Standards Institute, Sophia Antipolis, France, 1998.

- **European Securities and Markets Authority**

MiFID/MIFIR Discussion Paper, ESMA/2014/548, European Securities and Markets Authority, Paris, France, May 22, 2014.

- **U.S. Legislation**

H.R. 1678: National Positioning, Navigation, and Timing Resilience and Security Act of 2015, House of Representatives bill in the United States. Congress, Washington, D.C.

- **Federal Radionavigation Plan**

2014 Federal Radionavigation Plan (F, DOT-VNTSC-OST-R-15-01, U.S. Department of Defense, Department of Homeland Security and Department of Transportation, Washington, D.C., available from the National Technical Information Service, Springfield, Virginia, 2015.

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