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eLoran Points of Light

Preamble

There is considerable misinformation, outdated information, and obviously misleading information being promulgated as fact about Loran and Enhanced Loran (eLoran). This "Points of Light" paper is intended to respond to statements that have appeared in various media and on-line fora, some of which appear to be urban legend-type information, possibly based upon incomplete knowledge of the system, its history, or its capabilities. In most cases, this paper is limited to discussing non-military applications of GPS. That is, we do not include the advanced capabilities that military-grade receivers, antennas, software, and frequencies/codes provide. We are mainly addressing commercial users of GPS, which are estimated at more than 98% of the user community, and protection of Critical Infrastructure / Key Resource Sectors. In many, if not all cases, GPS and GNSS are interchangeable (certainly GPS and Galileo).

1. eLoran does not provide vertical navigation.

eLoran provides a 2D positioning solution, along with timing/phase, frequency, azimuth, one or more data channels, and built-in integrity. In the past, vertical guidance from radionavigation equipment has typically only been required by the aviation community, and then most generally at the approach and landing stage of aircraft. During the En-Route phase, vertical guidance is provided by barometric height and flight levels. More recently, a vertical component has become important to meet the FCC's new E911 indoor positioning requirements. Should vertical positioning be required, it is a simple matter to integrate a barometric altimeter into an eLoran receiver.

2. eLoran provides only Non-Precision Approach (NPA) capability.

According to the FAA's own reporting[1], eLoran is also capable of En-Route navigation. We expect eLoran to be of most benefit to the General Aviation community, and to the provision of an alternative timing source to UTC for the FAA's various ground infrastructure, including proposed Next Generation APNT solutions.

3. eLoran is only available in the USA.

It is generally accepted that eLoran was conceived in the United States, first at the USCG Electronics Engineering Center in Wildwood, NJ, and then at its successor Loran Support Unit at the same location. eLoran evolved into its current form with considerable input from the government, industry, and academic communities, as well as similar organizations in the UK. Many of the countries that monitored the progress of the R&D associated with moving from Loran-C to eLoran have now either started moving to eLoran or have plans to do so. At the outset, just

[1] FAA Final Report on "Loran's Capability to Mitigate the Impact of a GPS Outage on GPS Position, Navigation, and Time Applications" dated March 2004.

like GPS and radar, the military saw no use for Loran. It took considerable effort from a small team of dedicated individuals to bring radar, Loran, and GPS into the world.

4. eLoran is only available over land.

The coverage of eLoran, like its predecessor Loran-C, is omni-directional around the transmission sites. Coverage includes 2D for land, sea, and air. eLoran is available for positioning at distances over 800 miles. eLoran is available for timing/phase, frequency, and low-rate data delivery at distances over 1,000 miles. Availability distance is increased over saltwater paths. With appropriate algorithms, eLoran skywaves may be usable at distances exceeding 4,000 miles.

5. There is no international standard for eLoran.

There are globally recognized standards for Loran-C still in existence, mainly because Loran-C, or its Russian variant, Chayka, is still used in several countries. These international standards for Loran-C were essentially those developed by the USCG as the global operator of this DOD designed system. eLoran's signal structure and spectrum are essentially the same as Loran-C. Loran-C and Loran-D operated using the same standards. The current versions of the Loran Data Channel (LDC) are simply a variant of data channels that the USCG used in the past with Loran-C. There were no international standards for communications channels on the Loran-C signal, although two versions have been used: Clarinet Pilgrim and Two-Pulse Communications. However, there is a standard for one version of the LDC for eLoran, known as Eurofix (i.e., Tri-state pulse position modulation standardized by ITU-R.589-3 and RTCM SC-104), and standards were under development in the US for other LDCs when it terminated its Loran-C system. eLoran's major differences from Loran-C are operational, so the Loran-C standards already adopted by the international community require minimal changes for eLoran.

In 2018, SAE International's PNT (Positioning, Navigation, and Timing) Committee issued three new standards, SAE9990, SAE9990/1, and SAE9990/2, providing technical descriptions of the signal-in-space eLoran waveform and current data channel techniques that include explanations, and recommended practices.

6. eLoran requires a very large receive antenna.

"Very large" is not a good definition. The significantly higher frequencies of GPS as compared to Loran contribute to its ability to have smaller receive antennas. So, receive antenna size is relative. However, for most Critical Infrastructure / Key Resource sector applications, the receive antenna size is not a significant factor. For example, an eLoran e-field maritime, vehicle-mounted, or building-mounted receive antenna is comparable in size to that of a GPS receive antenna. An eLoran h-field receive antenna of dimensions 2" x 2" x .75" has been successfully developed and demonstrated. This is the type of antenna that would most likely be used for hand-held or aviation purposes. Unless physics law limits are approached, reducing the size of an eLoran receive antenna is a financial investment and order quantity problem, not a technology problem.

An indication of what is possible with miniaturization are the devices developed to receive WWV timing signals. These operate at 60 kHz, 40 kHz lower in the Low-Frequency Spectrum (30 kHz – 300 kHz) than eLoran, so would be even easier to develop at 100 kHz. As mentioned in NIST Technical Note 2187, low-cost radio-controlled clocks (RCC) are "relatively simple devices, containing a quartz oscillator, a small receiver permanently tuned to 60 kHz that decodes the incoming time code; and a small ferrite bar or loop antenna that is wrapped with a coil of wire". See the figure below, excerpted from NIST Technical Note 2187, showing an RCC and a wristwatch:

7. eLoran is affected by precipitation static ("p-static").

eLoran is not the only aircraft technology that precipitation static (aka "p-static") affects. P-static also affects VHF and HF communications, as well as ADF, VOR, and ILS systems. The effects of p-static are mitigated in different ways for different systems and frequencies. Tests conducted at the Ohio University, and sponsored by the FAA, proved that the effect of p-static on an eLoran receiver is mitigated through the use of a magnetic field (i.e., h-field) receive antenna.

8. eLoran is potentially threatened by EMI onboard an aircraft by local DC/AC power generators.

All electronic equipment is affected by EMI, including from DC/AC power generators. As with any other electronic equipment, proper installation and maintenance are key to optimum operation. Additionally, appropriate filtering or the use of ferrites will reduce or eliminate most problems.

9. The eLoran system consists of large infrastructure that needs to be maintained yearly.

eLoran is not alone in its need for maintenance. Every service provider infrastructure electronic and mechanical system requires some level of maintenance, even if it is just changing air filters. Examples include, but are not limited to, radar, AM, FM, TV, ILS, MLS, VOR, DME, TACAN, GNSS, GBAS, SBAS, OPNT, NextNav, Locata, PhasorLab, Seven Solutions, Satelles, Xona, Skyhook, TRX, Echo Ridge, R-Nav, radio beacons, lighthouses, and on and on.

It should be obvious that, when compared to GNSS, the cost of maintaining any ground-based infrastructure is minimal. When the redundant systems on board a satellite have all failed, the satellite is out of service until and unless a space mission is dedicated to its repair or replacement. This is not the case with terrestrial systems. They are easily repaired, modernized, or upgraded, often with minimal or no loss of usability.

The size of the infrastructure that exists on former Loran-C stations is related to their having been developed for fully manned use by the US DOD. Modern eLoran transmission sites – not stations – are designed for unmanned operation, and are significantly smaller in size, power consumption, HVAC requirements, and cost than previous versions. For example, a complete suite of eLoran technology now easily fits inside a standard 20-foot CONEX-type container.

The only large infrastructure remaining is the transmitting antenna. An optimum eLoran antenna – one that has good efficiency and cost versus size – is the 700-foot Top-Loaded Monopole (TLM). These antennas are actually similarly sized as those used in AM broadcast, submarine communications, and national time services (e.g., WWV, DCF77, R4, MSF). Loran antennas are designed for very long service lives (e.g., some Loran antennas have been in continuous service for over 60 years) in extremely poor environmental conditions. Loran antennas are constructed to survive hurricane, and other extreme weather, conditions. With proper maintenance, they have proven they can last for decades. Proper maintenance includes an annual mechanical and electrical inspection, periodic alignment adjustments (typically after major weather events; i.e., hurricanes), periodic re-lamping (typically concurrent with annual inspections), and re-painting about every five to seven years (depending upon the climate). Depending upon the occupational health and safety standards in the country in which the antenna is located, all tasks, except for structural repairs or modifications, can be performed when the antenna is live, or hot. This means that transmissions are available during almost all maintenance activities.

GPS also requires considerable ground infrastructure, and associated maintenance. See number 44 below.

10. eLoran vs. Racal HyperFix

In October 1940, a specification calling for radio navigation system with an accuracy of at least 1,000 feet at a range of 200 miles was developed by the US Army Signal Corps. The main application of this new system would be for naval convoys. Initial frequencies near 30 MHZ were evaluated, but the seawater ranges were determined to be too low. Comparative trials at different frequencies evaluating groundwave and skywave performance eventually led to the selection of 1950 kHz (or approximately 2 MHz) and from this Loran-A was successfully launched. Though successful in the maritime domain, the US Department of Transportation in the 1960s and 1970s saw a need for a system with greater modal application. Loran-C was designed with a lower frequency for improved propagation over land, extended range, and with cycle matching as opposed to envelope matching for improved repeatable accuracy.

At the same time, increased offshore surveying for oil and gas exploration demanded a highly accurate positioning system effective at large distances from shore. The UK-based Decca Navigator group responded with a system working on the same basic phase comparison principle as Decca but at a higher frequency to provide the improved accuracy, but at the expense of range. The system Hi-Fix was a precision hyperbolic positioning system with a maximum accuracy of 1.5 meters at a range of 50 kilometers from the transmitters. During its product life it was further improved, resulting in the Hi-Fix-6 variant and ultimately a third-generation system, HyperFix. Similar to Loran-A, HyperFix operated in the frequency band 1.6-3.4 MHz. The accuracy at the low end of the band was approximately 1.0 meter and 0.5 meters at the high end. Several other systems that also used the near-2 MHz frequency included Argo, Hydrotrac, and Raydist. This band is shared with amateur radio (160 meter band) and those users were subject to being classified as secondary users for many years. By contrast, the Loran-C band is protected worldwide.

By 1990, GPS/DGPS technology had matured and found application in hydrographic survey. None of the 2 MHz radio positioning systems could offer the accuracy and repeatability of DGPS, without having to set up a dedicated infrastructure. As GPS was provided free and provided everywhere, these application specific systems began to disappear very quickly.

11. Any RF device can be jammed or spoofed.

True. However, it is far easier to jam or spoof a very low-power signal, such as from GNSS, than a very high-power signal, such as from eLoran. Further, finding a GNSS jammer or spoofer in time for it to not affect operations continuity is very difficult, especially if the jammer or spoofer is sophisticated and/or mobile. On the other hand, the signal required to jam or spoof eLoran would need to be very strong and, therefore, easy to locate, especially if it is at a distance. At closer ranges – proximate to the receiver, for example – the effects of jamming or spoofing are easier, but are also less useful as they affect only one receiver and not a whole area.

12. eLoran interferes with itself, and receivers should be designed to handle this.

It has been understood since the advent of Loran that it is its own worst enemy. The signals are very powerful and cover very large areas. eLoran, which is an evolutionary development of Loran-C, suffers from the same problem. In-band and adjacent band interference is a concern for any RF system. However, Loran-C receivers have always been designed with mitigation techniques to reduce or eliminate the effects of self-induced interference. Modern eLoran receivers are even more capable. Suffice it to say that eLoran receivers designed today are just as technologically advanced and capable as any other RF receiver, including GNSS. eLoran "self-interference" is not an issue for modern receivers.

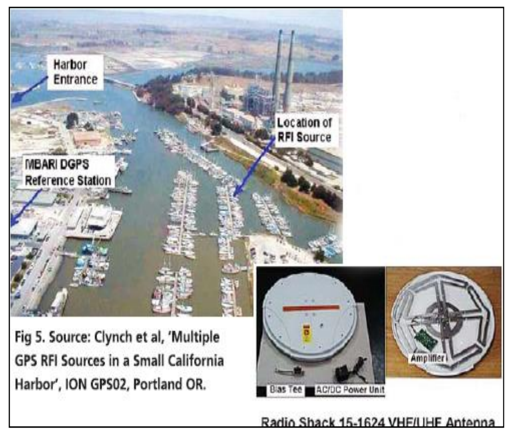
13. Control and Monitor stations can be cyber attacked.

A properly designed eLoran system would be no more prone to cyber-attack than any other system. For example, GPS has a global network of ground infrastructure interconnected with various means of communication that could be prone to cyber-attack. The former Loran-C system used a secure VPN for all of its communications. Modern eLoran systems would take advantage of similar technology. In certain cases, eLoran could also take advantage of military-grade telecommunications and software security solutions. eLoran transmission sites are capable of fully autonomous and unmanned operations for months at a time. They do not require typical telecommunications links to operate correctly. In fact, the Loran Data Channel (LDC), a very high power communication link built into the Loran signal, can be used for inter-site communications. This link can also be encrypted for added security. A modern system requires no "control" station; however, it is always prudent to have one or more Quality of Service "monitor" sites. Mechanical and electronic equipment status, tower lighting, environmental conditions, and security are easily monitored. Therefore, if a monitor site is desired, control technology is easily included.

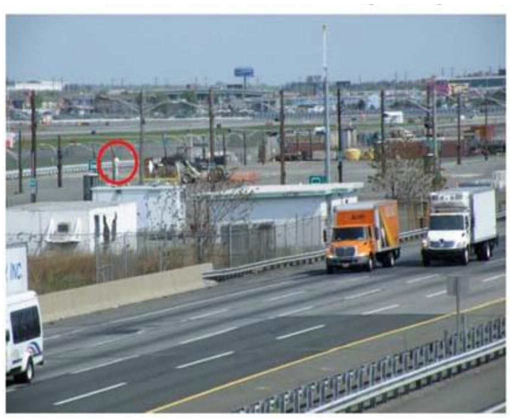
14. Incidences of intentional GPS jamming fall into the vandalism category.

This is an opinion not justified with facts. North Korea's GPS jamming of South Korea would not be considered vandalism. Stealing high-end cars in the UK would not be considered vandalism. Toll-lane cheating is not vandalism. A simple Google search would document a considerable number of intentional, and unintentional, jamming, and even spoofing, incidents. Presumably, intentional GPS jamming by friendly and hostile military forces would not be considered vandalism? The following are three incidents of unintentional GPS jamming, with resulting usability impact, that were not motivated by vandalism.

Leaving a switch on in San Diego



Watching TV in Half Moon Bay



Moonlighting near EWK

South Korea's Ministry of Land Transport and Maritime Affairs released the following depiction of North Korea jamming GPS across their common border:

The Central Radio Management Office of South Korea released the following table of disruptions:

Table 1: GPS disruptions for the past three years due to North Korean jamming (reported by the Central Radio Management Office of South Korea)

Dates	Aug 23–26, 2010 (4 days)	Mar 4–14, 2011 (11 days)	Apr 28 – May 13, 2012 (16 days)
Jammer locations	Kaesong	Kaesong, Mountain Kumgang	Kaesong
Affected areas	Gimpo, Paju, etc.	Gimpo, Paju, Gangwon, etc	Gimpo, Paju, etc.
GPS disruptions	181 cell towers, 15 airplanes, 1 battle ship	145 cell towers, 106 airplanes, 10 ships	1,016 airplanes, 254 ships

Various news agencies reported in early April 2016 that North Korea had resumed jamming into South Korea.

Jamming and spoofing incidents have been increasing every year, with major issues in the Middle East, Asia, the Suez Canal, and in nations proximate to Russia (e.g., Ukraine).

15. Following detection, it is easy to locate the source of the jamming signal.

For GNSS, this has not been the case to date. It took many months, and a concerted effort by several Agencies, to locate the signal unintentionally jamming the Newark (EWK) airport ILS system. See response to number 14. And this was unintentional jamming.

Even when we might know the jammers' locations, as in the case with North Korea, there is not much that can be done, "passively", about stopping it or reducing its impact.

16. eLoran does not compare well with DGPS/WAAS.

Of course not. This is like comparing apples and oranges. eLoran is not meant to compare with DGPS and WAAS ("SBAS"). These are *augmentations* of GPS, which were developed to improve its performance and integrity. Similarly, eLoran does not compare with RTK GPS, which is another *augmentation* to improve performance for special-purpose users. eLoran is also not meant to compare directly with GPS. Only another GNSS can compare head-to-head with GPS as they use the same frequency bands and very similar, space-based technologies (which also makes them susceptible to the same error sources). eLoran is meant to provide a complementary, multi-modal, diverse PNT solution for when GPS is not available or trustworthy. If GPS is not available, then DGPS and WAAS are not useable for PNT.

17. The cost of developing eLoran (aircraft) landing approaches is high.

It costs no more to develop an eLoran landing approach than it does for any other kind. Because of the safety, security, and integrity requirements, the time and effort required to certify approaches are costly, and are justifiably so. Several certified Loran-C approaches were developed prior to its decommissioning.

18. The cost of equipping aircraft with eLoran is high and provides no ROI for Commercial Aviation.

It is true that there may not be a reasonable ROI for Commercial Aviation, especially for international flights. There is, however, a need for an alternative timing solution for the FAA's Alternative PNT program, and eLoran could fill this need. Additionally, there is very likely a good ROI for the General Aviation community. Loran-C receivers were available for aviation in the past so there is no reason that eLoran receivers could not be available as well. During the development of eLoran by the FAA and USCG, several receiver manufacturers were involved with developing and testing aviation-grade eLoran receivers. It is our expectation that eLoran would be integrated into existing aviation receiver models or Flight Management Systems (FMS) as an additional sensor. The cost of integrating an eLoran engine into an existing receiver or FMS would be incrementally small. Retrofitting existing aircraft with eLoran technology may be made more cost effective by using existing antennas on the fuselage, such as the ADF antenna or those already used for storm scopes.

19. GPS outages of greater than one hour are unlikely.

A DOT Federal Register Notice[2] requested information on "the positioning, navigation, and/or timing performance required for a complementary PNT capability during a disruption of GPS that could last for longer than a day". We presume the DOT selected this disruption duration based upon some concerns that it might be "likely". The risk of an outage is also only one area of concern. The other concerns that require consideration are the impact of an extended outage, which would

[2] Docket Number DOT-OST-2015-0053. Complementary Positioning, Navigation, and Timing Capability; Notice; Request for Public Comments.

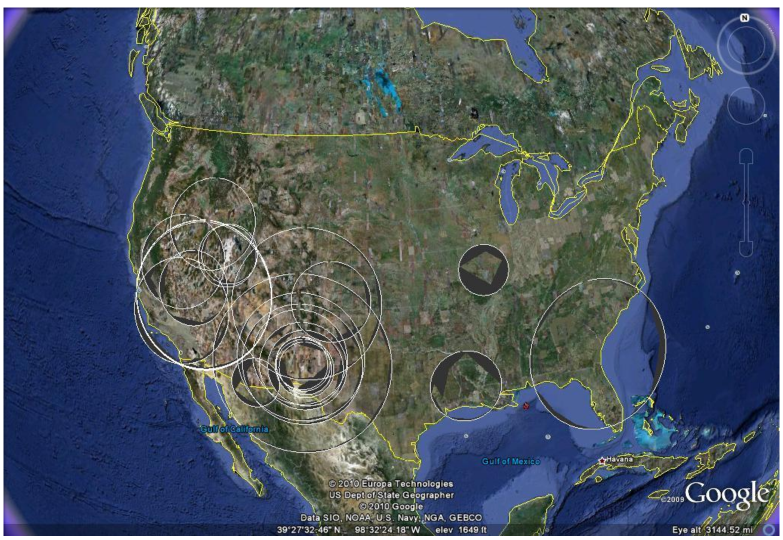
be very significant in terms of economic impact and safety of life. Further, it has been shown that even the shortest GPS outages can have long lasting rippling effects for user applications.

The GPS SVN-23 13.7 microsecond timing anomaly of January 26, 2016, lasted about five hours and twenty minutes, and affected at least 15 other satellites in the constellation.

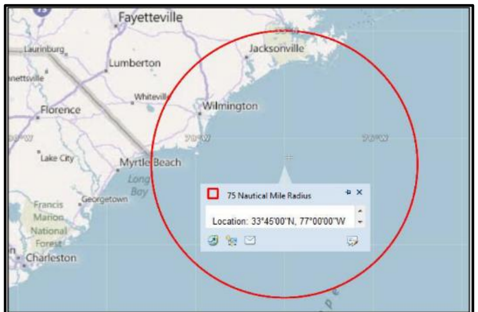
20. GPS outages over large areas of the nation are unlikely.

GPS remains the gold standard for PNT, and we should do everything possible to keep it that way. As Dr. Brad Parkinson has suggested, we should "Protect, Toughen, and Augment" GPS. However, no system is infallible. Consider the outage of Russia's entire GLONASS for over 12 hours in April of 2015. It was presumably unplanned, and probably considered unlikely as well.

The below graphic, courtesy of the FAA, indicates there are intentional wide-spread outages/unavailability over large areas of the nation. The fact that these outages are necessary for testing does not obviate the fact that they exist.



Below are other examples of GPS unavailability, and their probable impact, attributable to planned testing. On the left is an example of intentional outages off the east coast of the United States, with an impact radius of 75 nautical miles. On the right is an example of intentional outages, required for a military jamming exercise by the Royal Navy in Scotland, and its impact on local fishing.



From Feb 03 through Feb 10, 2012, daily from 1600 EST to 2145 EST, the GPS navigation signal may be unreliable due to testing on GPS frequencies used by shipboard navigation, aviation and handheld systems. Systems that rely on GPS, such as E-911, AIS and DSC may be affected at an approximate testing center point of 33 45.00N, 77 00.00W, with an impact radius of approximately 75 NM from center point.

10 October 2011 Last updated at 11:20 ET

Military jamming of GPS in Scotland suspended

By Steven McKenzie
BBC Scotland Highlands and Islands reporter

Jamming of global positioning signals (GPS) during Europe's largest military exercise has been suspended, following complaints from fishermen.

The Royal Navy issued warnings in September and October that GPS in parts of Scotland would be disrupted during Exercise Joint Warrior.

But Western Isles fishermen said the first they knew was when their equipment went offline last Friday.

The Royal Navy said the military would seek to address their safety concerns.

Joint Warrior is held twice a year and jamming of GPS in April drew no complaints, according to the military.

The Royal Navy said all appropriate actions were taken to warn of the disruption during this year's second exercise, including a guide which was issued on 7 September.

The guide gives the locations and timings for the jamming of GPS.

The Scottish government confirmed it received the guide in September and put it on its website, but a spokeswoman added that it was the Ministry of Defence's (MoD) responsibility to distribute the information.

Temporary jamming of GPS is routinely practiced in exercises, the Royal Navy said

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RAF to receive 14 new Chinooks

MoD orders 14 Chinook helicopters

The GPS SVN-23 13.7 microsecond timing anomaly of January 26, 2016, lasted about five hours and twenty minutes, and affected at least 15 other satellites in the constellation. It affected critical infrastructure, such as telecommunications, aviation, and broadcast, around the world. Here is a great video of the event: https://www.youtube.com/watch?v=ZjnK8GmSvnc.

Whether outages are planned or unplanned, they do occur. They are very likely. We should focus on what complementary PNT solution(s) are available *when* GPS outages occur.

21. Timing can be backed up using an atomic clock that is calibrated hourly.

True. Full-scale cesium-based Primary Reference Standards (PRS) or Chip-Scale Atomic Clocks (CSAC) certainly provide good timing backup. However, they are expensive and they are for holdover purposes only. They require an initial timing calibration, and periodic synchronization to an external timing source. In other words, they do not know what time it is unless they are told. GPS and eLoran are not holdover solutions; they are direct sources of time, phase, and frequency. GPS and eLoran are provided UTC timing directly from the USNO, and then can promulgate that time over very wide areas (i.e., globally and continent-wide, respectively). eLoran service outside the United States might rely on UTC from another national timing laboratory, such as UTC(NPL) in the UK or UTC(OP) in France.

22. eLoran is a backup for timing.

eLoran is a great backup for timing, phase, and frequency. eLoran is not an oscillator, or clock. It is not a hold-over device. It is the only other Stratum-1e timing source in the US, besides GPS. eLoran gets its time, synchronized to UTC, from the same source as GPS. Note that neither GPS nor eLoran generate their own time; they simply pass it along from the sovereign UTC source (i.e., USNO) via Primary Reference Standards that are on the GPS satellite or at the eLoran transmission site. eLoran does not require an external input for time, as does a Primary Reference Standard.

23. The marketplace should determine eLoran's acceptance and implementation. The government's role should consist of making the system available.

Agreed. This is true of any technology. The government should ensure that Critical Infrastructure / Key Resource Sectors have multiple, complementary PNT solutions available to provide resilience. The government should ensure a lead executive agency is empowered and properly funded to provide a complementary PNT solution. The government's own reports have repeatedly acknowledged that eLoran is that solution.

24. eLoran should not be considered a substitute for GPS.

Another GNSS is the only real substitute for GPS. As of this writing, the other GNSS available are Russia's GLONASS, China's BEIDOU, and Europe's Galileo.

25. We should not divert resources from preserving and improving the existing GPS system.

Agreed. As Dr. Parkinson suggests, we should "Protect, Toughen, and Augment" GPS. Irrespective of its military benefits, GPS is a phenomenal economic enabler, both nationally and internationally. We should continue to preserve and improve it.

26. GPS-enabled devices employ high-stability clock oscillators, inertial navigation, and map-matching algorithms.

So do eLoran-enabled devices. In fact, a fully integrated device would include GNSS, eLoran, INS, and map-matching algorithms (as necessary). Whatever can be done with a GPS receiver can also be done with an eLoran receiver. The outputs of an eLoran receiver are identical to that of a GPS receiver: 1 PPS, 10 MHz, and NEMA. Once there is a signal-in-space that will be available for ten or more years, industry will resurrect their eLoran receiver programs and begin to capitalize on various integration methods.

27. Can eLoran be reliable?

eLoran is based upon previous versions of Loran (i.e., -A, -C, and -D), which has a proven track record of providing reliable PNT service over almost 70 years of continuous operation worldwide. When properly equipped, Loran transmission stations typically operate at or very near 100% availability. Loran-C was the primary PNT system for the DOD from 1957 until 1994, and was used extensively afterwards nationally and internationally until GPS took over in the commercial world.

28. What about Accuracy, Availability, Integrity, and Continuity?

An FAA/USCG "Murder Board" in 2002 generated the following requirements for eLoran Accuracy, Availability, Integrity, and Continuity to be an acceptable complement to GPS.

	Accuracy	Availability	Integrity	Continuity
Loran-C Definition of Capability* (US FRP)	**0.25 nm (463 m)**	0.997	10 second alarm/ 25 m error	0.997
FAA NPA (RNP 0.3) Requirements**	**0.16 nm (307 m)**	**0.999 – 0.9999**	**0.9999999 (1 x 10-7)**	**0.999 - 0.9999 over 150 sec**
US Coast Guard HEA Requirements	**0.004 - 0.01 nm (8 – 20 m)**	**0.997 - 0.999**	10 second alarm/ 25 m error (3×10^{-5})	0.9985 – 0.9997 over 3 hours

* Includes Stratum 1 timing and frequency capability
** Non-Precision Approach Required Navigation Performance

Subsequent research, development, and testing showed eLoran's ability to meet, or exceed, all of these requirements.

29. eLoran requires more testing.

The modernization and upgrade of the US Loran-C system to eLoran was a congressionally mandated program jointly executed by the FAA and USCG from 1997 to 2009, and funded at over $160M. 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 UK for several years and upgrade programs are in progress in the UK, Republic of South Korea, Kingdom of Saudi Arabia, and China. 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.

30. eLoran provides the US Government with the opportunity to maintain world leadership in the development of resilient PNT systems and solutions.

The US Government continues to maintain world leadership in GNSS-based PNT through its GPS. However, the Government has abdicated its leadership in a resilient PNT ecosystem and relies solely upon GPS for its primary PNT needs. Even the government's "PNT" outreach website was renamed from www.pnt.gov to www.gps.gov! eLoran, along with other non-GNSS solutions required for a resilient PNT ecosystem, is a necessary component of the US Government regaining its PNT leadership role.

31. Stable and transparent public policy commitments on signal availability and access conditions are required to develop market confidence.

Agreed. Market confidence only comes if there is a long-term commitment to funding and operation. Long-term in this case is defined as more than ten years, and preferably 20 years. This type of commitment sends industry the correct message that they can invest in applications of the technology, and lets users know those applications will be available for years to come.

32. eLoran cannot provide the same level of PNT performance as GPS.

It depends on what is meant by "performance". Accuracy, availability, integrity, and continuity have already been addressed. We already know that eLoran is not global (it is continental), that it is not 3D (unless aided with an altimeter), and that it is not as accurate as GPS. However, eLoran is not a competitor to GPS, nor should it be. The only PNT solutions that can offer the same level of performance as GPS are other GNSS. eLoran is a complementary system. eLoran offers comparable PNT accuracy, proof-of-time, proof-of-position, continuity of operations, and graceful performance degradation. eLoran is the only terrestrial PNT solution that is multi-modal, very wide area (i.e., continental), and completely independent of GPS. Note that many, if not all, space-based PNT alternatives depend upon GPS for timing.

33. There are substantial costs associated with developing ASF databases.

It depends upon the accuracy required from the ASF data. ASF databases are set up in grids of varying dimensions, depending upon the type of terrain and the level of precision. For example, grid sizes can be very large over all seawater paths as there are no changes in ASF, but might want or need to be smaller near airports, ports and harbors, or major metropolitan areas. ASF databases can be generated with the application of modeling and simulation algorithms using ITU conductivity data. More precise ASF databases can be developed using almost any transportation method. Data can be collected by any platform, and is very simple to do. Once the data is collected, it can be managed centrally and provided to receiver manufacturers, just like data that is provided to GPS receivers. ASF databases can also be developed in real time using an integrated GNSS/eLoran receiver and/or with crowd-sourced information.

34. ASF databases have not yet been developed, and cost estimates for building and operating eLoran do not account for ASF development.

ASF databases have been developed for parts of the world, including many areas within the US and UK The cost for building ASF databases has been included in ROM costs provided to various Agencies within the Government. When GPS/GNSS are available and trustworthy, they can become the basis for easily and economically developing eLoran ASF databases.

35. eLoran accuracy does not support GPS applications that require more precise positional location data, such as: high-precision agriculture, surveying, automotive navigation, public safety/law enforcement, and Intelligent Transportation Systems.

This is essentially correct if we presume that "precision" refers to meter-level, centimeter-level, or better, accuracies. However, neither does "raw" GPS. Discerning PNT users require various levels of augmentation to GPS to reach their desired performance. For high-precision agriculture, it is RTK. For surveying, it is special-purpose, multi-frequency, high-cost equipment. For automotive navigation, it is Lidar, INS, moving maps, wheel counters, etc. This is not to suggest that GPS is not more accurate than eLoran; it simply means that we should compare apples with apples.

Un-augmented GPS is more accurate than eLoran, but still not accurate enough for "precision" applications. eLoran can also take advantage of the same augmentations as GPS (i.e., INS, moving maps, etc.) to improve its accuracy. For example, differential eLoran (similar to differential GPS) can provide a significantly improved level of precision for public safety/law enforcement, especially in areas where GPS is unavailable (i.e., indoors, in urban canyons, and under foliage). There are R&D efforts under way that may provide additional improvements to eLoran precision. At some point, however, the physics differences between a high-frequency and low-frequency signal will bound the possible precision. The key point is that GPS and eLoran together are much better than either are alone.

36. The aforementioned applications could not function reliably using eLoran positional data alone (i.e., high-precision agriculture, surveying, automotive navigation, public safety/law enforcement, and Intelligent Transportation Systems (ITS)).

eLoran was not designed, and will probably not provide sufficient accuracy, for high-precision agriculture or surveying. We would expect the agriculture and surveying communities to continue to use the most accurate technology available, and that is currently GPS with augmentations (e.g., DGPS or WAAS).

eLoran, in its standard configuration, will be only modestly effective for automotive navigation. For example, eLoran would most likely not be able to inform a user in which lane they were driving on Interstate 95 (I-95). However, eLoran would be able to inform a user that they were driving north or south on I-95. It would provide proof-of-position, and azimuth.

eLoran's existing accuracy could be useful to public safety/law enforcement. For example, as proof-of-position or proof-of-time, under foliage, in urban canyons, and other locations where GPS might be unavailable or untrustworthy. In many cases, having some idea of position when the primary solution is unavailable is better than falling back to manual methods or nothing at all. Yes, GPS provides two-meter positioning accuracy worldwide. But if 10 meters or 100 meters were available (in a port/harbor or field/desert, respectively), would it not be useful to a user?

Similarly, for Intelligent Transportation Systems, eLoran may not be able to provide the accuracies necessary for self-driving/autonomous vehicles. However, it is our understanding from speaking with autonomous vehicle companies that they also do not want to rely on any "external" PNT solution that could be unavailable or untrustworthy, and thereby compromise passenger safety. GPS will certainly continue to be used for general-purpose vehicle navigation, but not necessarily for autonomy for on-road applications. Here again, eLoran provides a check on the relative accuracy of the positioning solution, and could also be used to help geo-fence vehicles inside or outside some boundary.

Not all ITSs require highly accurate positioning accuracy. For example, for Positive Train Control, we expect eLoran would be useful in providing proof-of-position and speed inputs into over-speed or moving-block incursion algorithms. Alongside GPS, eLoran and another positioning or timing input could provide a "Resilience Triad™" for these types of applications.

37. eLoran cannot provide centimeter-level and nanosecond-level accuracies.

Correct, for centimeter-level accuracy. eLoran cannot provide centimeter-level accuracy. However, neither can GPS in an un-augmented form. Note that centimeter-level accuracy is not required except by a small subset of users (albeit very important users).

Not necessarily correct for nanosecond-level accuracy. eLoran is capable of sub-tens of nanoseconds accuracies around differential eLoran reference station sites (i.e., reference sites similar to DGPS). It is fully capable of providing sub-500 nanosecond accuracies outside a differential eLoran reference site coverage area. Legacy (i.e., 4G, LTE-A) telecommunications timing/phase requirements are +/- 500 nanoseconds, and future (i.e., 5G) requirements are +/- 300 nanoseconds. Most Critical Infrastructure / Key Resource Sector timing/phase requirements are on the order of one microsecond to one millisecond, easily achieved by eLoran using differential capability. Note again that nanosecond-level accuracy is not required except by a small subset of users (albeit very important users).

38. Aviation Technical Standard Orders (TSO) and Advisory Circulars (AC) have been cancelled. Any new eLoran standards will have to be reviewed for their acceptability in terms of accuracy, integrity, availability, and continuity.

This is correct. Shortly after the US decommissioned its Loran-C service, TSOs and ACs were cancelled. However, eLoran is built upon Loran-C's foundation, and resurrecting and reusing the formerly approved documents would not be as prodigious a task as starting from scratch.

39. Integration is a challenge because of the "relatively large" E-field and H-field antennas.

It depends into what devices eLoran would be integrated. General-purpose (i.e., maritime, land-mobile, aviation, location based, and timing/phase) eLoran antennas are comparable in size to GPS. Integrating an eLoran into small form-factor devices, such as smart phones, would require additional R&D. Note that Loran-C units were available in hand-held models, and were even the most widely used positioning device in the first Gulf War (mainly because the GPS constellation was not yet completely operational and GPS receivers were not as available as they are today). Picture the first mobile phones (i.e., "bricks") that used retractable or stubby (E-field) antennas. This was state-of-the art through the 1990s. The application of current antenna design should result in smaller SWAP-C eLoran E-field and H-field antennas. The key driver is economic order quantity, not technology.

40. There is no eLoran technology, or Loran-C technology is obsolete.

It is true that once the US terminated its Loran-C program, and Canada followed suit, that the industry was decimated. UrsaNav, LLC continues to develop and sell innovative TRL-9 Loran/eLoran technology. And this is 21st century technology that takes advantage of all the modern software, hardware, and algorithms used by other advanced technology solutions. Russia, China, and Iran also have existing technology, or are developing technologies, in this area. Other countries who are currently purchasing, or investing in the development of, (e)Loran technology are the UK, Kingdom of Saudi Arabia, and Republic of South Korea. If eLoran continues to be adopted as a complement to GPS, then we would expect the market to recover, especially for receivers and related products. eLoran is an enabler of technologies, and a differentiator, and we expect many companies would include it in their offerings.

41. There is value in beginning a discussion on eLoran now.

The discussions, studies, reports, and committees have been occurring since the early 1990's. Every government, academic, and industry report – worldwide – has concluded that GPS/GNSS is vulnerable, and that eLoran is the best alternative/complement. The value is in implementing the solution that has already been studied, tested, demonstrated, and approved: eLoran.

42. eLoran requires GPS as an external time source.

This is not correct. It is important to note that both GPS and eLoran require external time sources. In both cases, they are Stratum-1e sources, which means they get their timing from a source of UTC, which in the US would be the USNO.

Let's describe how time is derived and disseminated from a well-designed eLoran transmission site. This eLoran transmission site would have local and remote time scales. The transmission site time distribution solution uses the local time scale as its core. The local time scale consists of three "ensemble" Primary Reference Standards (typically, Cesium-Beam Oscillators). The remote time scale collects time from any external references the customer selects. The remote time scale could include one or more inputs, such as: GPS, GNSS (i.e., Galileo), Two-Way Satellite Time Transfer (TWSTT), Two-Way Low-Frequency Time Transfer (TWLFTT), direct fiber, microwave, "hot clock", and the like. Remote time scale inputs are not directly coupled to the local time scale, and are monitored and weighted to determine their usefulness as observables to the local time scale.

The USCG has demonstrated that an eLoran transmission site can maintain its local time reference within tens of nanoseconds of UTC for at least 70 days with no access to any remote time scale.

43. While eLoran may be less vulnerable to jamming, it is still susceptible to atmospheric interference.

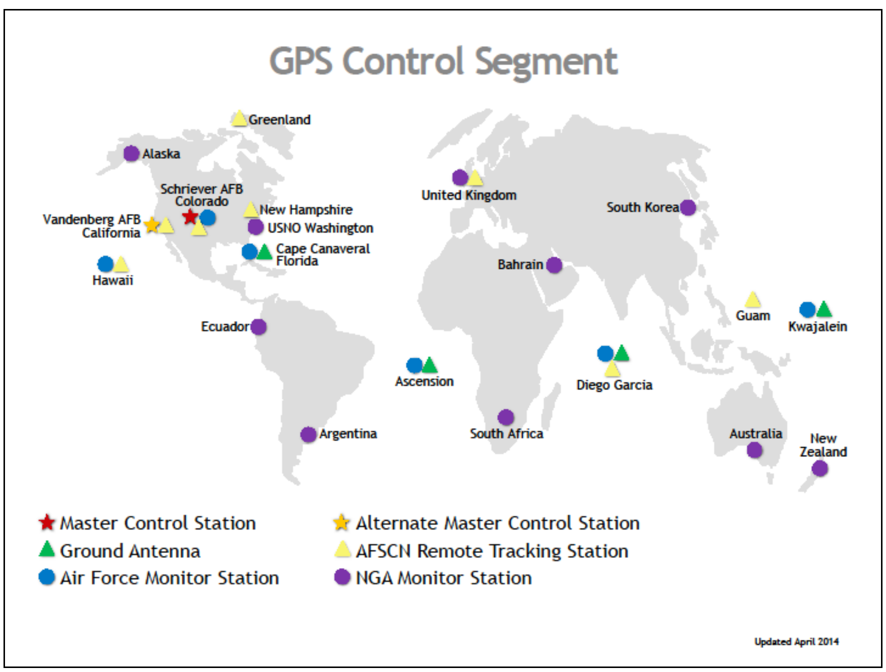
All RF solutions are susceptible to atmospheric interference: GNSS, (e)Loran, Radar, TV, AM/FM, microwave, etc. The key is that the interference usually affects dissimilar systems in different ways. Because GNSS and eLoran are at "opposite" ends of the frequency spectrum, they will respond differently to different atmospheric effects. That is one reason why they are such good complements. GPS is space-hardened and radiation hardened. eLoran can also be radiation hardened (as was Loran-C in the past). One key difference is that it is much quicker and cheaper to mitigate any problems with eLoran because it is terrestrial.

44. "Also, you would have transmitters located in shacks kind of sitting out by themselves, which are susceptible to a terrorist attack or to general vandalism."

eLoran is the latest in a long line of Loran solutions that were initially developed by the US DOD and UK MOD for use during WWII. Loran-A, -C, and -D supported operations throughout every military engagement since WWII, including Korea, Vietnam, and the Gulf War. For example, during the Persian Gulf War, the US Army purchased 6,000 Loran-C receivers to allow vehicle commanders to determine their location in the nearly featureless desert.

Interestingly enough, the DOD-designed Loran facilities, whether in fixed or mobile applications, were very survivable and as easily protected as any terrestrial technology. Loran technology was never located in “shacks”. It was always in very well-designed, fixed structures, or MILSPEC transportable containers. The fact that the transmission sites can be placed “out by themselves”, that is far away from the users, actually provides a measure of stand-off distance for additional protection. As we have seen in the news since even before 9/11, everything and every place is susceptible to terrorist attack. Multiple transmission sites with overlapping PNT coverage adds another layer of protection. Take one or more sites out, and you still have many others left.

Let’s not forget that even GNSS requires some ground infrastructure, as can be seen in the attached “GPS Control Segment” graphic. Most of this infrastructure is located outside the US, often in remote locations. How is this better than eLoran?



45. Locating jammers would likely be less expensive than building eLoran.

There are several technologies that can assist with locating jammers. However, it is unlikely that we can assign enough resources to locate all the jammers all the time. Because most jammers are mobile, how do we effectively assign resources to chase them down? Even with laws in place to restrict the purchase and use of jammers, they continue to proliferate and become more sophisticated. Even US Government attempts to shut down internet sales sites have been unsuccessful. How do we find a jammer until it is turned on? We have laws against texting and driving, against not wearing seat belts, and against drinking and driving. Yet, we still have thes problems. Let's not rely on "good citizenship" to protect our critical national infrastructure and key resource sectors. As Dr. Parkinson suggests, let's "Protect, Toughen, and Augment" GPS.

46. "Using eLoran as a backup for GPS is analogous to backing up the Dallas Cowboys with a high school football team."

We acknowledge that the only true backup to GPS is another satellite-based solution. Unfortunately, other satellite solutions have the same vulnerabilities as GPS. And they all have augmentations, whether they be space-based or ground-based, to try and fill gaps in, or enhance, their services. eLoran may not be as good, head-to-head, as GPS. However, it is the very best, wide-area, multi-modal complement to GPS that exists. When your primary PNT solution is not available or not trustworthy, you have a choice. You can choose a slightly less accurate PNT solution, or no PNT solution. Which would you choose?

Loran-C was the predecessor to GPS, and the DOD's acknowledged global source of PNT for 37 years (1957-1994). eLoran is even better than Loran-C.

47. eLoran is an entirely new concept, with its inception in the 1990's.

Although eLoran started coalescing in the 1990s into the standardized system that it is today, it has its roots much further back in history. All the concepts that form the foundation of eLoran have been around for decades. Like many other great ideas, SWaP-C constraints, impact on installed bases, slowly changing standards, available technology, lack of computing power, etc., slowed the progress of change. For example, although the "Loran Data Channel" terminology came into play in 1999, modulation techniques have been used since the 1960's.