eLoran to serve as GNSS backup

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***Abstract*—This document gives an overview on the suitability of eLoran as GNSS backup for position and timing. GNSS may become increasingly a matter of concern for various fields of application, such as maritime navigation, aviation and drones, land transportation, timing and synchronization as in telecom, finance and power grids, and defense. Focus is on accuracy and stability and on integrity. Important topics are given for eLoran usage, such as ASF, skywaves, reradiation and sensor fusion.**

Keywords—eLoran, GNSS backup, Resilience, Maritime, Aviation, Land navigation, Timing, Finance, Telecom, Power grid, Defense, Sensor fusion, ASF, Skywave, Reradiation.

I. Introduction

With this document an overview is presented on the suitability of eLoran as GNSS backup. GNSS is increasingly unreliable for various fields of application. Thus we are investigating how to apply eLoran to serve as GNSS backup for timing and position, in order to switch to eLoran when GNSS is detected as becoming unreliable. Although eLoran is at the moment not available everywhere on the globe, in East-Asia it is already widely available. And in Europe it is starting to be re-developed (lead by the UK). Further interest in eLoran is growing widely.

In this document we investigate the requirements and suitability for various application fields. Each field is having its own requirements, not the least due to the dynamics of the ships, planes, cars, drones, and others.

The hereafter considered and subsequently elaborated application fields of interest are:

- Maritime navigation (coastal, harbours).
- Aviation (approach, landing).
- Land transportation (road, rail, air / drones).
- Timing & synchronization (telecom, finance, power grid).
- Critical infrastructure (not elaborated).
- Defense (soldiers, vehicles). This is not further elaborated, but certainly interesting enough for (portable) eLoran receivers.

Focus is not only on accuracy and stabilty, but also on integrity i.e. how fast and reliable can an eLoran receiver detect – e.g. with help of additonal sensors – that the timing and/or position determined my not be reliable enough and switch back to some form of save backup mode is required.

Next some topics for eLoran receiver design are being presented, of importance for obtaining e.g. sufficient accuracy:

- ASF problems.
- Skywave problems.
- Sensor fusion.
- Bridges, oil storage tanks, nearby large ships.

The information in this document is obtained by working for a long time in the eLoran arena, by studying the public domain, and by discussions with potential end-users. This document may be useful for further discussions.

II. Field of Maritime Navigation

Near-coast and harbour navigation involves:

- Narrow channels.
- Turning basins.
- Berthing operations.
- Traffic separation schemes.
- Shallow water and grounding risk.
- High vessel density.

Harbour approach/manoeuvring and near-coast operations (attention to offshore wind farms) require:

- Accuracy: 5–10 m (95%) (harbour), 20–50 m (95%) (near-coast).
- Stability: sub-meter to a few meters of drift over minutes.
- Update rate: 1 Hz minimum, 2–10 Hz preferred for tight manoeuvring.
- Integrity: alarm within 10 seconds.
- Continuity: >99.9% availability.

Maritime Operation	*Accuracy*	*Stability (Drift)*	*Update Rate*	*Integrity*
Harbour manoeuvring	5–10 m	<1–3 m	2–10 Hz	<10 s
Harbour approach	8–20 m	<5 m	1–2 Hz	<10 s
Near-coast navigation	20–50 m	<10 m	1–2 Hz	<30 s
Coastal transit	50–100 m	<20 m	1 Hz	<30 s

Notes:

- *These numbers come from IALA, IMO Resolution A.915(22), and real-world pilotage practice.*
- *Integrity means that eLoran receiver must be able to decide within e.g. 10 sec that position is reliable, or next switch back to a safe mode.*

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For near-coast and in harbour operations, ships need:

- 5–20 m accuracy.
- 1–3 m short-term stability.
- 1–10 Hz update rate.
- Integrity alarms within 10–30 seconds.

eLoran can meet most of these requirements, and with modest upgrades (dynamic ASF, higher update rate, ensor fusion) it can meet all requirements except perhaps the most demanding dynamic-positioning use cases.

III. Field of Aviation

Approach and landing requirments depend on type of approach, in terms of:

- Accuracy (horizontal & vertical) – at approach: horizontal: < 100m (95%), vertical: not required (barometric) altimeter, with eLoran altitude computation is not feasible, update rate 1-2 Hz.
- Integrity (probability of undetected error).
- Continuity (probability the system stays available).
- Update rate (how often position is refreshed).
- Latency (i.e. how old the data is).

Approach Type	*Required Accuracy*	*Update Rate*	*Integrity*	*eLoran Suitable?*
VFR landing	100–200 m	1 Hz	Low	✔ Yes
Non-Precision Approach (NPA)	<100 m	1–2 Hz	Medium	✔ Possibly
APV (LPV, LNAV/VNAV)	4–40 m	5 Hz	High	✖ No
ILS CAT I	4–16 m	5–10 Hz	Very high	✖ No
ILS CAT II/III	<2–10 m	10–20 Hz	Extremely high	✖ No

Notes:

- *Vertical accuracy required: < 2-4 m during landing.*
- *Aviation sees eLoran as a continuity system, not a precision landing system.*
- *Aviation integrity requirements: Alert within 6 seconds (APV), with 1-2 seconds (CAT II/III)*
- *Receiver certification: DO-229 equivalent.*

IV. Field of Drones

Drones have some of the tightest PNT (Position, Navigation, Timing) requirements of any mobile system, especially when flying low, close to buildings/trees/ powerlines, with high agility, fast, or autonomously. Their needs are very different from ships, aircraft, or cars because drones operate in 3D, close to obstacles, and often without human intervention.

Drones typically require:

- Horiz. accuracy: 0.1–5 m depending on mission.
- Vert. accuracy: 0.1–3 m. Not possible with eLoran.
- Stability: < 0.5 m drift over seconds, <2 m over minutes.
- Update rate: 5–20 Hz for safe flight.
- Integrity: < 1–2 seconds for autonomous operations.
- These requirements are far stricter than for ships or manned aircraft.

Drones are increasingly being used for delivery of packages, for industrial inspection (power lines, wind turbines, high buildings and towers). Drones are under development for Urban Air Mobility / Air Taxi. Drones will increasingly be required to transmit their position (in 3D) to Flight Control offices.

Drone Type	*Horiz. Accuracy*	*Vertic. Accuracy*	*Stability*	*Update Rate*	*Integrity*
Hobby	1–3 m	1–2 m	<1 m	5–10 Hz	<3 s
Industrial	0.5–2 m	0.3–1 m	<0.5 m	10–20 Hz	<1 s
BVLOS Delivery	1–5 m	1–3 m	<2 m	5–10 Hz	<1 s
UAM / Air Taxi	<1 m	<0.5 m	<0.5 m	20 Hz	<0.5 s

The high agility of drones certainly make it harder for an eLoran receiver to obtain sufficient accuracy for navigation. But it can certainly serve as a strategic fallback to keep the drone from flying away or crashing in a GNSS outage, using:

- Sensor fusion.
- Intertial navigation.
- Vision systems.
- Barometric altimeters or alternatives.

A serious problem with present drones is that the high power propellor engines are seriously disturbing the radio field for eLoran receivers.

V. Field of Transportation on Land

Land transportation has much looser PNT (Position, Navigation, Timing) requirements than aviation or drones — but stricter requirements than maritime in some contexts (especially lane-level driving, rail, and autonomous vehicles). Below is an industry-grade breakdown of the accuracy, stability, and update-rate requirements for road vehicles, rail systems, and autonomous mobility.

The requirements are given for:

- Road Transportation (human-driven vehicles).
- Heavy Trucks, Logistics, Fleet Management.
- Rail Transportation (Signalling, ERTMS, Train Control).
- Autonomous cars (Level 3-5).

Sector	*Accuracy*	*Stability*	*Update Rate*	*Integrity*	*eLoran Suitable*
Road (cars)	5–20 m	<5 m drift	1–5 Hz	<20 s	✔ Yes
Logistics / Trucks	5–10 m	<5 m	1–5 Hz	<10 s	✔ Yes
Rail (ERTMS)	<8 m	<2 m	5–10 Hz	<1 s	✔ Yes
Autono-mous cars	<1 m	<1 m	10–20 Hz	<1 s	✖ No

Note: with rail transportation eLoran reception may seriously be hindered by the high-current overhead lines. And re-radiation?
Note: These data are tailored for location in the Netherlands, where dense infrastructure, tunnels, and urban environments make GNSS resilience particularly important.

VI. Topic: Skywave Problems

Even though the main skywave pulse seams to be less of a problem, and arrives later than ground wave, weak skywave components have been reported to arrive earlier due to: Multipath, Partial reflections, Layered ionosphere conditions. These can subtly change the shape of the front flank, thus disturbing Time Of Arrival (TOA) measurements based on the front flank.

Condition	*Skywave effect on front flank*	*Range error*
Daytime	Very small	<5 ns (1.5 m)
Nighttime (normal)	Small	5–20 ns (1.5–6 m)
Nighttime (disturbed ionosphere)	Moderate	20–50 ns (6–15 m)
Geomagnetic storm	Large	50–100 ns (15–30 m)

VII. Topic: Sensor Fusion

IMU (Interial Measurment Unit) chips can dramatically improve eLoran accuracy, stability, and integrity—not by making eLoran more precise on its own, but by filling in the gaps where eLoran is weak: short-term stability, update rate, and noise. The combination is far more powerful than either system alone.

Below is a summary of how IMU + eLoran sensor fusion works. Chips are available for rotation (gyroscope), acceleration meter, magnetometer and others.

IMU chips give eLoran:

- Sub-second stability (INS smooths eLoran's e.g. 1 Hz updates).
- Higher effective update rate (INS may run at 100–1000 Hz).
- Short-term accuracy boost (INS bridges eLoran noise).
- Better integrity (INS detects jumps, spoofing, skywave errors).
- Improved navigation in urban/indoor/blocked environments.

With it, the eLoran receiver with an INS (Inertial Navigation System) resulting in:

- Long-term drift correction.
- Absolute position reference.
- UTC timing reference.

Together, they form a hybrid PNT system that is far more resilient than GNSS alone.

Metric	*eLoran Alone*	*INS Alone*	*Fusion (typical)*
Short-term accuracy	8–20 m	0.1–1 m (drifts)	3–10 m
Long-term accuracy	8–20 m	Drifts to 100+ m	8–20 m
Stability (seconds)	3–10 m jitter	<1 m	<1 m
Stability (minutes)	Stable	Drifts	<3 m
Update rate	1 Hz	100–1000 Hz	100–1000 Hz
Integrity	30–60 s	N/A	5–10 s

Note: INS is very stable over seconds, but drifts over minutes. eLoran is stable over minutes, but noisy over seconds.

Thus such fusion may yield a major improvement, especially for:

- UTC timing reference.
- Maritime near-coast navigation.
- Land transportation.
- Drones (coarse fallback).
- Timing applications (INS may help to detect timing jumps).
- UTC timing reference.

VIII. Topic: Reradiation by Bridges, Oil Storage tanks, Nearby large Ships

Their reradiation effects on the ground waves, important to eLoran receivers are:

- Steel bridges, oil tanks, cranes, ships, and buildings can thus distort the eLoran groundwave, but only locally and only within tens to hundreds of meters of the structure.
- They do not create true "skywave-like" reflections — the wavelength is far too long for that.
- Instead, they cause groundwave perturbations, eddy-current absorption, and phase shifts, causing the eLoran receiver computing an incorrect Time-Of-Arrival signal.

These effects are real, measurable, and important for e.g. ASF mapping — but they are not long-range reflections looking like skywave. At 100 kHz (wavelength ≈ 3000 m):

- A steel bridge (50–500 m) is tiny compared to the wavelength. But a km's long bridge is something different.
- Oil tanks (20–100 m) are also relatively tiny (but field of tanks can be large).
- Even a skyscraper (with metal in construction or concrete) is only ~0.03 λ tall.

This means (as the physics simply doesn't allow it):

- They cannot act as specular reflectors.
- They cannot create delayed multipath like GNSS.
- They cannot produce skywave-like echoes.

Even though they can't reflect low-frequency waves like mirrors, large metal structures interact strongly with low-frequency electromagnetic fields. They may cause:

*Eddy-current absorption***:** Large conductive objects absorb low frequency energy and re-radiate it weakly. Effects are: reduced signal amplitude, slight phase delay, local ASF-like bias (1–20 µs in extreme cases).

Groundwave phase distortion: The groundwave sticks to the earth surface. When it passes near a large metal object,

boundary conditions change. Effects: phase shift of tens of nanoseconds, equivalent to meters of position error.

Local field perturbation: large metal structures distort the electro-magnetic field lines. Effects are: local ASF-like "bubbles". Errors typically within 100–300 m of the structure.

Shadowing and re-radiation: Not reflection — but induced currents can re-radiate a weak, phase-shifted field. Effects are: small TOA-bias, not a separate multipath signal.

Structure	*Typical ASF disturbance*	*Range error*
Steel bridge	10–100 ns	3–30 m
Oil storage tank	5–50 ns	1.5–15 m
Container ship	10–80 ns	3–24 m
High-rise building	5–30 ns	1.5–9 m
Industrial plant	10–200 ns	3–60 m

Note: These are local effects — not long-range skywaves.
Note: Harbours are full of metal: cranes, ships, containers, tanks, bridges. ASF seems to vary rapidly in these environments.

IX. Topic: Usage of eDLoran

Standard eLoran monitoring station data (ASF) is distributed by DLoran via the eLoran transmitter Eurofix "data channel" at 30-60 bits/sec. Thus limited capacity to broadcast ASF data to eLoran receivers at users end (at max. range typical 800 km).

With eDLoran monitoring stations data (ASF) distribution can be done by using 4G/5G mobile or LPWAN and Internet as "data channel" at e.g. >1 kbit/sec (max. range horizon 50 km). Typical ASF "monitoring area" is 20-50 km wide per low-cost monitoring station. Monitoring station data and eLoran user receiver data is further sent via Internet to an eDLoran Network Control Center, and ASF correction specification is returned via this channel to the requesting eLoran receiver at user end (*see lit.ref. GPS World, June 2014, eDLoran: The Next-Gen Loran*).

eDLoran uses low-cost, low-power monitoring stations spaced:

- 20–50 km apart in coastal areas.
- 50–100 km in-land.

Traditional eLoran monitoring stations may be spaced at e.g 100 km apart — too coarse for fine ASF corrections.

Metric	*Standard eLoran*	*eDLoran*
Accuracy	20–50 m	5 m
Timing	10–30 ns	5 ns
Integrity	30–60 s	5 s
ASF correction	Static	Dynamic

An additional advantage of the two-way eDLoran concept is, that for the coverage area the ASF-tables in the eDLoran receivers are not required anymore.

X. Conclusions

It is presented how various application fields have different requirements and suitability aspects for eLoran receivers to meet for time and position measurements in order to be applicable as a backup for GNSS. For some fields of application time accuracies (related to UTC) are most important, while for others position determination is the focus of interest.o reach acceptable accuracies, eLoran receivers may require longer signal integration times (seconds), which however can be conflicting with e.g. required output update rates.

To alleviate the eLoran receiver limitations, integration with additional sensors for acceleration and rotation is very likely necessary.

Moreover, for the various fields of application the eLoran receiver, optionally assisted by integrated sensors, must be able to detect within required time limits that the time and/or position output is reliable (integrity detection). These specifications are sometimes further specified in RAIM (Receiver Autonomous Integrity Monitoring) requirements.

Next a summary of the above elaborated position and/or timing accuracy needed for the various application fields, is given together with a first indication about the eLoran suitability to serve as backup for GNSS.

Application Area	*Position Accuracy Needed*	*Timing Accuracy Needed*	*eLoran Suitability*
Maritime	50 m (5 m in/near harbour)	Low	Very good
Aviation	<100 m (<5 m for landing)	<100 ns	Good (not for landing)
Drones	0.5-2 m (0.3-1 m vertical)	<100 ns	Insufficient?
Road Transport	20–100 m	Low	Good
Rail	8-30 m	<100 ns	Good
Power Grid	Not critical	<50 ns	Very good
Telecom	Not critical	<30–50 ns	Very good
Finance	Not critical	<100 ns	Very good
Ports/Logistics	5–20 m	<100 ns	Good
Critical Infrastructure	50–100 m	<50 ns	Very good
Defense	5–20 m (soldier, vehicle)	<10 ms	Good

Notes: eloran receivers must mitigate ASF errors and include sensor fusion. GNSS jamming near ports is increasingly common; eLoragn provides resilience.

A most important issue to deal with in the design and testing of the eLoran receiver is focus on the ASF problem, and how to mitigate the ASF ground wave propagation influences. eLoran ground wave signals travel over land and sea with different propagation speeds, and thus arrive in shifted times-of-arrival, affecting time and position accuracies. Actual ASF-maps, generated by the eLoran receiver itself with help of GNSS when usable, must be available in each eLoran receiver, requiring sufficiently large memory space in the eLoran receivers.

To be able to reach sufficienty high accuracies with eLoran for some application fields, it may be advised to investigate the potential of the eDLoran concept.