**IALA Guideline G-XXX**

**On**

**the Performance and Monitoring of**

**eLoran/Chayka Services in the Frequency Band90 – 110 kHz**

**Draft Edition**

**October 2015**

International Association of Marine Aids to

Navigation and Lighthouse Authorities

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Document Revisions

Revisions to the IALA Document are to be noted in the table prior to the issue of a revised document.

|  |  |  |
| --- | --- | --- |
| **Date** | **Page / Section Revised** | **Requirement for Revision** |
|  |  | Acceptance of previous track changes to establish |
| Oct 2015 | New document | IALA policy on Guidelines and Recommendations |
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**IALA Guideline on the Performance and Monitoring of a eLoran/Chayka Service in the frequency band 90-110 kHz**

**THE COUNCIL**

**NOTING t**he function of the IALA with respect to Safety of Navigation, the efficiency of maritime transport and the protection of the environment,

**NOTING ALSO** IMO resolutions A.915(22) on Maritime Policy for the Future Global Navigation Satellite System (GNSS) and A.1046(27) on World Wide Radionavigation System,

**NOTING FURTHER** ITU-R Recommendation M.589-3 Technical characteristics of methods of data transmission and interference protection for radionavigation services in the frequency bands between 70 and 130 kHz,

**RECOGNISING** the need to ensure that eLoran/Chayka services are operated in accordance with certain minimum standards that take into account relevant ITU‑R Recommendations and IMO Resolutions,

**RECOGNISING ALSO** that the minimum standards should include the signal format, reference datum, availability, continuity, integrity, accuracy, signal monitoring, range and coverage, status reporting, validation, and the publication of information about the system,

**HAVING CONSIDERED** the proposals made by the e-Navigation Committee:

**ADOPTS** the Minimum Standards for the Performance and Monitoring of eLoran/Chayka Services in the frequency band 90 – 110 kHz set out in the annex of this guideline; and

**RECOMMENDS** National Members and other appropriate Authorities providing, or intending to provide eLoran/Chayka services in the frequency band 90 – 110 kHz, to use the Minimum Standards set out in the annex to this guideline.

Annex

Minimum Standards for the Performance and Monitoring of eLoran/Chayka Services in the frequency band 90 - 110 kHz.

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# Introduction

Enhanced Loran (eLoran) is a low-frequency, long range Terrestrial Radionavigation System, capable of providing positioning, navigation and timing (PNT) service for use by many modes of transport and in other applications including maritime. It is a PNT system operating at an assigned frequency of 100 kHz utilizing pulsed signals from widely spaced transmitting stations in which the receiver’s position is determined by the measurement of the times of arrival of these pulses.

An eLoran system includes the following elements:

* A number of stations transmitting synchronised PNT signals, incorporating a data message
* An identified service area, in which the signal propagation characteristic have been surveyed
* Where higher levels of accuracy are required, reference stations are installed, to input corrections into the transmitter data message

Service providers are opting to provide eLoran services as part of a robust PNT solution, as eLoran is dissimilar and complementary to GNSS services. The aim of this Guideline is to enable service providers to deliver, monitor and assess the performance of eLoran services in a common manner.

System performance is based on the assumptions that the system provider conforms to these Guidelines and that the user equipment meets the design and installation standards as specified.

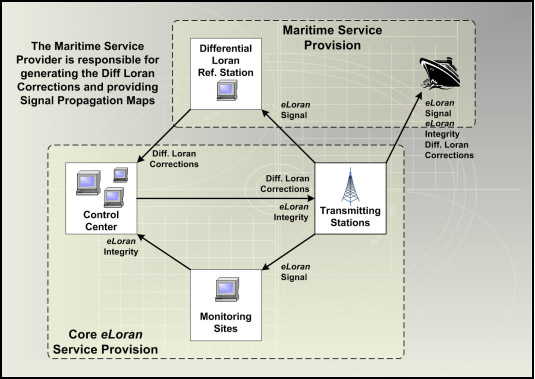


Fig 1: The service architecture for eLoran and the components required.

## Document overview

### Chapter 2: Performance Requirements

The chapter defines and details the overall performance requirements for the broadcast with main focus on IMO resolution A.1046 (27). The performance requirements are absolute accuracy, integrity, continuity, availability and coverage.

### Chapter 3: Technical Aspects

The chapter provides technical aspects for a service provider to develop and maintain eLoran services. The chapter gives a guideline on how to fulfil the performance requirements.

### Chapter 4: Operational Aspects

The chapter gives the service provider an understanding on how to operate and validate an eLoran service during its lifetime with respect to the performance requirements.

### Chapter 5: Publication of Information

An eLoran service provider should inform the user about the system, and this chapter deals with which data to publicise.

### Chapter 6: References

### Appendices

Annexes includes examples on calculations, technical implementations etc. The following annexes are included:

Appendix A: Signal definitions

Appendix B: Service definitions

Appendix C: Abbreviation

Appendix D: Receiver Algorithms

Appendix E: List of stations and GRI

# Performance Requirements

IMO Resolution A.1046 (27) details the requirements on World-Wide Radio Navigation Systems (WWRNS) considering vessels operating in the Ocean and harbour entrances, harbour approaches and coastal waters. The requirements are described by accuracy, integrity, availability, and continuity, as defined in Appendix B. Table 1 summarizes the requirements specified in A.1046 (27), whereby the requirement on availability is given as signal availability describing the availability of radio navigation signals in the specific coverage area (see IMO A.915(22)).

**Table 1** **Requirements for eLoran systems [based on IMO A.1046 (27) & IMO A.915(22)]**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | System Level | | | | Service Level | |
|  | Absolute Horizontal Accuracy (95%) | Integrity | | | Signal Availability  (2 years) | Continuity  (over 15 minutes) |
|  | Alert Limit | Time to Alarm | Integrity Risk |
| Area | m | m | s | % | % | % |
| Ocean | < 100 | N/A | N/A | N/A | > 99.8 | N/A |
| Harbour entrances, harbour approaches and coastal waters | < 10 | 25 | 101 | 1 x 10-5 | > 99.8 | 99.97 |
| 1 *Generation of integrity warnings in cases of system malfunctions, non-availability or discontinuities;* | | | | | | |

Receiver equipment for the eLoran system intended for navigational purposes on ships with maximum speeds not exceeding 70 knots[[1]](#footnote-1) shall meet the minimum performance requirements outlined in Table 1.

# Technical Aspects

This chapter deals with the technical implementation of eLoran service in the frequency band 90-110 kHz, whose use enables the fulfilment of performance requirements given in Chapter 2.

## eLoran signal provision

The eLoran service provider will provide the eLoran signal as defined in Reference [7].

The eLoran signal comprises two basic components:

* The pulsed waveform, in which the standard zero crossing point (Figure 2) is used as the time-stamp from which timing and hence ranging from the transmitter is derived.
* The data component, which is constructed by modulating the eLoran waveform.

The signal construction, data format and transmission characteristics are detailed in ITU-R Recommendation M.589-3(Ref. 1) (to be updated)

The eLoran Waveform is the basis of timing and hence ranging. Each transmitter broadcasts a group of eight to or ten pulses, in a pattern synchronised with adjacent transmitters. Each pulse consists of a 100 kHz carrier that rapidly increases in amplitude in a prescribed manner and then decays at a rate which depends on the particular transmitter and antenna characteristics.

Signal Power is expressed in terms of Peak Envelope Power in kilowatts.



Figure 2: The Loran pulse waveform with the standard zero crossing

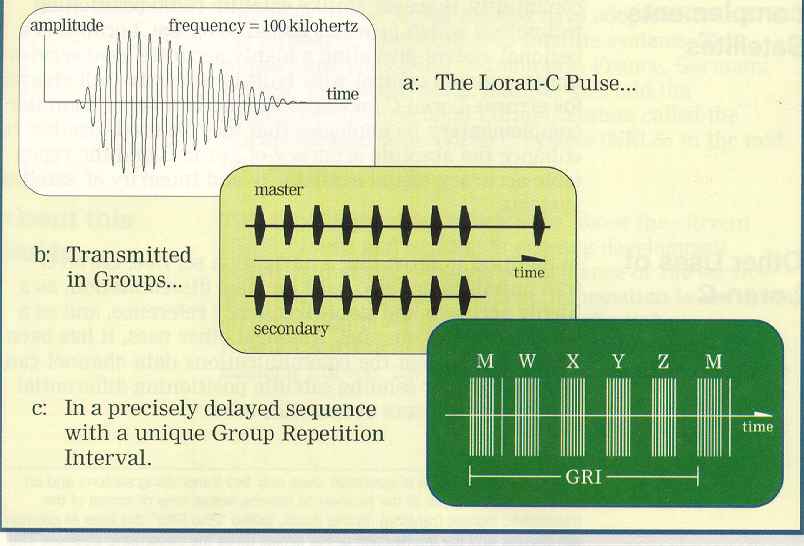


Figure 3: The Loran waveform, transmitted in groups with unique GRI

## Time Synchronisation

eLoran signals should be synchronised to Universal Coordinated Time (UTC).

The Signal Performance Standard [ref] requires:

* The 10 second exponential average of all navigation (not modulated) shall be within 25 ns of UTC;
* The 1 second exponential average of all navigation (not modulated) shall be within 100 ns of UTC;
* The peak to peak variation of 5 second exponential average of all navigation (not modulated) shall be less than 10 ns within a 20 minute period [ref].

## The eLoran Data Channel

One of the essential features of eLoran is the additional functionality provided by the eLoran Data Channel, should transmit as a minimum:

* Time of Day (UTC), Leap Seconds offset between eLoran time and UTC.
* Differential eLoran corrections for temporal variations in ASF for maritime & timing users.
* Almanacs, containing information regarding new transmitters, chains, monitors, Group Repetition Intervals (GRI) etc., and makes it possible to change systems without rendering previous eLoran receivers obsolete

With the option to provide other messages, depending on system performance, which can include:

* Authentication messages
* Differential GNSS corrections
* Inform users of problems with other stations.
* Messages that explain to eLoran users why a certain signal is being blinked. (e.g., Master blink)
* Any other relevant data

## ASF measurements

In order to provide greater accuracy, the service provider will need to provide a database of Additional Secondary Factors (ASF) [ref] for specific applications, such as Harbour entrances, harbour approaches and coastal waters..

Appendix D2 and D3 contain a description of the ASF data publication format and its use. This also includes the publication of “ASF measurement error” values that can be employed in Horizontal Protection Level (HPL) computations.

## Differential eLoran reference stations

Differential Loran reference stations are required near to Harbour entrances, harbour approaches and coastal waters where <10m (95%) accuracy is required. These reference stations monitor the real time ASF values and by knowing their true location can provide ASF correction information to the transmitter for promulgation to the user.

Differential eLoran reference stations also provide integrity by detection of erroneous signal conditions and feedback to the transmitter/control centre.

Differential eLoran reference station timing is achieved by synchronising to UTC. This is engineered by use of a local atomic clock standard, updated by external time reference.

## Transmitter Performance

To transmit eLoran information, a ~200m mast is recommended, with 24 top loading elements and an appropriate earth mat. The transmitter output power shall be in the region of 200kW-1MW. The local infrastructure must provide reliable power and broadband connectivity with the appropriate security.

It is normal practice to duplicate the transmitter, timing and control units and power supply. The use of Uninterrupted Power Supplies to prevent outages in the event of short term loss of power supplies is strongly recommended.

The performance of the LF transmitter and its antenna can be affected by weather conditions and an automatic Antenna Tuning Unit (ATU) should be used to minimise such effects.

There are well-established methods for the measurement of radiated power, field strength and antenna efficiency (Ref. 15). Lightning protection is highly recommended due to the antenna height.

## Receiver Performance

In order to use eLoran, users should operate a receiver capable of calculating an eLoran position in accordance to the technical specifications set out in *IEC 61108-1* andincorporating a current ASF correction database.

Earlier generation Loran receivers will be able to utilise any core PNT signals received, but will not be able to benefit from ASF mapping or the eLoran data message corrections.

# Operational Aspects

An eLoran service provider should:

* continuously monitor the service and manage any disruptions
* inform users of important properties of the service and communicate warnings about service disruptions to the user
* manage any maintenance work or changes to the service in such a way where service disruption is minimized and the users are provided with advance warning
* verify the service is performing according to specifications and provide such information to users

## Reference Datum

The datum used should be stated in each service providers publications. WGS84 is typically used by most service providers. It should be noted that use of the incorrect datum could result in errors of up to several hundred metres.

## Monitoring

On-site monitors should be provided at each transmitting station, to check the transmitted signal and the data content.

Additional signal monitoring is recommended using receivers placed at sites within the coverage area, to validate broadcast site RF and signal performance. Communication lines to a central control and monitoring site may link integrity monitors. Data may either be logged on station and downloaded periodically or passed directly to the central control site. It is recommended that this data be archived for a period sufficient to meet local litigation requirements.

Information on each eLoran monitor site shall be provided to a control centre. The information will include:

* + ID of the Monitor Site
  + Location of the Monitor Site
  + Nominal ASF Values at the Monitor Site
  + Reference ECD Value(s)
  + Applicable approaches monitored by the reference station
  + Acceptable eLoran transmitters
  + The format is repeated for each monitor site and eLoran station combination in each operational area

## Publication of information

Individual Service Providers are encouraged to publish service descriptions, including coverage predictions and system performance statistics; examples are given in references 18 to 23.

In addition to the information contained in the standard message types, described in Section 1, notice of current or planned signal unavailability should be provided to users through the appropriate service (e.g. coastal radio station, VTS, Navtex, Safetynet etc.)

Wherever practicable, information on scheduled and unscheduled off-air periods should be promulgated to users as follows:

Table 4

|  |  |  |
| --- | --- | --- |
| Scheduled maintenance | Date and expected downtime | One month in advance is recommended, but at least 1 week in advance is mandatory |
| Unscheduled outages | Expected downtime | As soon as practicable and not more than 1 hour after the occurrence |

IALA Guidelines on Bilateral Agreements and Inter-Agency MOU’s on the Provision of DGNSS services in the frequency band 283.5 kHz– 325 kHz contains examples of such documents. The examples include guidance on the information that should be exchanged between co-operating agencies and, where appropriate, the circumstances and timing for it to be exchanged.

IALA will maintain a master list of eLoran stations on the Internet. Input to the master list will be prepared by each Service Provider. IALA will provide an electronic template that should be used for initial entry of station data and assembly of the complete Service Provider submission. After initial submission, Service Provider will be responsible for updating their own sections of the IALA master list. The process to incorporate changes will require each Service Provider to provide a complete, updated section of the list for all the eLoran sites that they operate. Each complete submission will appear exactly as submitted.

The service provider is recommended to publish that they follow IMO Resolutions and IALA Recommendations for the provision of eLoran, giving emphasis to the provision of integrity information.

Service provider needs to tell the user at which ports, or within which areas, they can expect to receive eLoran signals and where they can expect to meet the harbour requirements.

## Performance verification

It is recommended that the service provider measure the performance components continuously in order both to detect service disruptions and to determine if the performance requirements are being met over an extended period of time.

Performance should take account of the declared eLoran service area. In order to maximize the combined performance service providers should:

* coordinate the scheduling of maintenance work so that the effect on coverage is reduced
* exchange information about service disruptions
* exchange information about achieved performance

### Coverage verification

Nominal ranges of stations over seawater paths should be published at a stated signal-to-noise level (-10dB) (Ref. ITU-R M.589). Published coverage diagrams are normally based on software modelling predictions and should be verified by measurements. The modelling process can be quite complex and difficult, especially over mixed land/sea paths. Advice regarding modelling can be sought through IALA. In predicting coverage, each service provider should establish the required field strength by giving consideration to the following factors:

* Radiated power,- Antenna system configuration, including horizontal and vertical polar diagrams.
* Land paths - Additional attenuation over land should be calculated from current ITU-R curves and practice applicable at 100 kHz (Refs. 6 & 7).
* Fading due to skywave propagation of the station’s signal - At night the field strength at every point in the coverage area should be not less than that specified at the nominal range for at least 95% of the time. Night-time field strengths may be calculated in accordance with references 8, 9 & 10.
* Atmospheric noise - Assumed levels of atmospheric noise should be in accordance with current ITU-R data and practice applicable at 100 kHz. It is recommended that the noise level be that which is not exceeded more than 95% of the time on average throughout the year (Refs. 11 & 12).
* Precipitation static - In those areas where precipitation static is known to be a significant problem, an appropriate factor should be added to the atmospheric noise (Ref. 13).
* Man-made noise - In those situations, such as harbours, where man-made noise is significant in comparison with natural noise sources, the local man-made noise level should be taken into account (Ref. 14).
* Interference - The protection ratios to be applied are those of the ITU-R (Ref. 1), appropriate to the type of interfere and the frequency separation. Both groundwave and skywave propagation should be considered.

### Availability verification

The availability standard adopted for an eLoran service is related to the techniques used in planning and implementing the service.

**Availability** is defined in IMO Resolution A.915 (22) (Ref. 4) as:

*“The percentage of time that an aid, or system of aids, is performing a required function under stated conditions. The non-availability can be caused by scheduled and/or unscheduled interruptions.”*

**Signal availability** is defined as the availability of a radio signal in a specified coverage area.

Mathematically this can be written as:

**Availability (A)\* = \_\_\_\_\_MTBO\_\_\_\_**

##### MTBO + MTSR

Where*:*

***MTBO*** *= Mean time between outages; based on a 30 day averaging period*

***MTSR*** *= Mean time to service restoration; based on a 30 day averaging period*

This accounts for scheduled and unscheduled service interruptions, i.e. preventative and corrective maintenance.

\* Alternatively expressed as UP TIME/TOTAL TIME where TOTAL TIME = 30 days

### Continuity verification

Inherent in a radionavigation service is the capability to provide accurate position fixing and integrity information without interruption. Interruptions to eLoran deny vital information to the users and, if frequent, erodes user confidence in the ability of the service to provide that information. The numbers of unusable events, not the length of the usable periods, determines continuity performance.

In the event that a healthy and monitored eLoran site begins to experience intermittent failures (i.e. failures separated in time by a period less than one continuity time interval (CTI)), the period of intermittent operation would be counted as a single failure event for continuity purposes.

**Continuity** in the coverage area can be measured (1) at the broadcast site, (2) by the use of a far field monitor, or (3) by using a combination of these methods. Continuity is based upon the mean time between failures as measured over a two year period and a 15 minute continuity time interval.

**Continuity events**: All unscheduled non-momentary unusable events described in the availability section are considered failures. Unlike availability, continuity does not count scheduled maintenance events as failures. Since public notices are provided for all scheduled maintenance events, user should be aware of such planned outages and plan the voyage accordingly. limits without interruption during a specified period (normally short term).

The equation below refers to an availability type calculation, i.e. the average over the continuity time interval (CTI) that the service is available or the probability that the service is available at any instant during the CTI. It is more appropriate to calculate the probability that the service is available throughout the CTI. The suggested approach is given below:

Assuming the service is functioning at the beginning of the operation, then the probability that it is still functioning at a time (t) later is:

C = exp (-t/MTBF)

This is the standard expression for reliability and excludes scheduled outages (i.e. uses MTBF) assuming that planned outages will be notified and the operation will not take place. The probability that the service will be available after a time CTI, that is the continuity is then:

C = exp (-CTI/MTBF)

If MTBF is very much greater than CTI, this can be approximated to:

C = 1 – (CTI/MTBF)

Where*:*

***MTBF*** *= Mean time between failures; based on a 2 year averaging period*

***CTI*** *= Continuity time interval; in the case of maritime continuity, equal to 15 minutes*

There is no need to include the availability at the beginning of the time period of the operation because if there is no service, then the operation will not commence.

### Integrity verification

Give example of how to calculate the integrity of the service? How can a service provider know they have achieved the 10s TTA? Should results be presented per port?

### Accuracy verification

Where differential eLoran are provided to improve the accuracy level e.g. in Port and port approach areas, the absolute horizontal accuracy should be better than 20m at the 95% probability level within the published coverage area.

To achieve this level of accuracy, the effective centre of the transmission antenna should be surveyed to a 2D accuracy of better than 1 metre. The time of emission requires to be corrected for the length of transmission lines between transmitter and antenna.

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# ANNEXES

## ANNEX A Definitions

## eLoran pulse

The pulse and specifically referenced points or parameter of the pulse are identified in Figure 3.2.



Figure 3.2 Loran Pulse.

## Loran Data Channel

The Loran Data Channel (LDC) allows the eLoran system to meet higher position accuracy and time synchronization applications. Regardless of the type of communication scheme[[2]](#footnote-2) used, the LDC shall convey corrections, warnings, and signal integrity information to the user’s receiver via the eLoran transmission. The data transmitted may not be needed or provided for all applications but will include at a minimum:

* The identity of the station[[3]](#footnote-3);
* The identity of the monitor site[[4]](#footnote-4);
* Absolute time based on the Coordinated Universal Time (UTC) scale; leap-second offsets between eLoran system time and UTC;
* Warnings of anomalous radio propagation conditions including early skywaves; warnings of signal failures, aimed at maximizing the integrity of the system;
* Differential eLoran corrections, to maximize accuracy for maritime and timing users; and

The data transmitted may not be needed or provided for all applications but may include:

* Differential GNSS corrections:
* Almanac message on changes of Loran transmitting and differential monitor sites;
* Messages that allow users to authenticate the eLoran transmissions; official-use only messages;
* Tell users that another station is transmitting but it is transmitting improperly (tattle tale).
* Messages that explain to eLoran users why a certain signal is being blinked. (e.g., Master blink)

## Additional Secondary Phase Factor Grid

The data developed during the survey of Harbor Entrance and Approach (HEA). This grid information and data will be developed and given to the receiver manufacturer by the service provider. This grid data is used along with the differential-Loran data to provide the accuracy required for HEA. More information on the data and composition of this grid is found inEnhanced Loran (eLoran)LORIPP/LORAPP Draft Specification of the eLoran System, Rev. 4.0

## eLoran Receiving Equipment

A device, using a nominal antenna, which processes eLoran signals.

## Nominal eLoran Antenna

The nominal antenna for a receiver shall be specified by the manufacturer. In carrying out the specific test procedures, the signal levels at the space coupling node shall be related to the field strength in proportion to the effective height of the nominal antenna.

There are two possible types of nominal eLoran antenna

3.1.1.6.1 H-field antenna

Definition to be developed

3.1.1.6.2 E-Field antenna

Definition to be developed

## Legacy Loran-C Receiver

The legacy Loran-C receiver is typically chain-based which can not use signals from different GRIs. However later versions developed after the Chain-to-chain timing tolerances were minimized did allow from some cross chain position fixing capability. The legacy receiver does not significantly benefit from the changes made to create the eLoran system and derives no benefit from the eLoran Data Channel.

## All-in-View

eLoran uses the Time of Arrival (TOA) of signals (relative to UTC) from individual transmitting stations to determine position. In an eLoran receiver, each transmitter may contribute a range to the position solution.

## Error budget

The amount of signal generation, propagation factors, and receiver processing induced effects that would degrade the position fix beyond acceptable application limits.

## 2drms

The 2-drms (twice distance root mean square) statistical error refers to the radius of a circle, centered at the true position that contains at least 95 percent of the measured or estimated positions.

# APPENDIX B Service Definitions

Several definitions like the “Terms” are taken directly from the nominative references and other documents for ease in understanding this MPS and to avoid confusion.

**Acquisition**

Acquisition is defined as the processing of eLoran signals to obtain a position fix within the required accuracies. The Time to Fix (TTF) for a specified mode is defined as the time needed from “power on” to process eLoran signals to obtain a position fix within the required accuracy of that mode.

**Time to Reacquisition Fix (TTRF)**

Time to Reacquisition Fix for a specified mode is defined as the time needed beginning from restoration of a lost signal to nominal state to obtain a position fix within the required accuracy of that mode.

##### Accuracy[[5]](#footnote-5)

Accuracy is the degree of conformance between the estimated, measured, or desired position or the velocity of a platform at a given time and its true position or velocity. Radionavigation performance accuracy is usually presented as a statistical measure of system error. Accuracy is a statistical measure of performance; therefore, a statement of the accuracy of a navigation system is meaningless unless it includes a statement of the uncertainty in position that applies. Accuracy can be specified in terms of one or more of the following definitions:

* *Predictable.* The accuracy of a position in relation to the geographic or geodetic coordinates of Earth.
* *Repeatable*. The accuracy with which a user can return to a position whose coordinates have been measured at a previous time with the same navigation system.
* *Relative.* The accuracy with which a user can measure position relative to that of another user of the same navigation system at the same time.

Another factor related to accuracy is fix dimension, which gives “accuracy” in more than one measurement axis. The term *fix dimension* defines whether the navigation system accuracy is a linear, one-dimensional line-of-position or a two- or three-dimensional position fix. The ability of the system to derive a fourth dimension (e.g., time) from the navigation signals is also included. A vital factor is a system’s ability to limit fix ambiguity. System ambiguity exists when the navigation system identifies two or more possible positions of the user, with the same set of measurements, with no indication of which is the most likely correct position. The potential for system ambiguities should be identified with provision for users to identify and resolve them.

##### 

##### Integrity

Integrity is defined as the ability of a system to provide timely warnings to users when the system should not be used for navigation.

##### Availability

Availability is the ability of the system to provide the required function and performance at the initiation of the intended operation. Availability is also an indication of the system’s ability to provide usable service within the specified coverage area. Signal availability is the percentage of time that navigational signals transmitted from external sources are available for use. Availability is a function of the technical capabilities of the transmitter and receiver, as well as the effects of propagation. A major factor in availability is system capacity given a specified fix rate without a situation that would cause the signal to be unusable. System capacity is the number of users that a system can accommodate simultaneously. The fix rate is defined as the number of independent position fixes or data points available from the system per unit time.

##### Continuity

Continuity is defined as the capability of the total system (comprising all elements necessary to maintain a user’s position within the defined space) to perform its function without non-scheduled interruptions during the intended operation. The continuity risk is the probability that the system will be unintentionally interrupted, and not provide guidance information for the intended operation. More specifically, continuity is the probability that the system will be available for the duration of a phase of operation, presuming that the system was available at the beginning of that phase of operation. The factors that affect availability also affect continuity.

##### Coverage

Coverage is the result of the preceding four factors. Coverage is the geographic area where the application-specific radionavigation system requirements (e.g., RNP 0.3 or HEA) for integrity, accuracy, availability, and continuity parameters are satisfied at the same time. System geometry, signal power levels, receiver sensitivity, atmospheric noise conditions, and other factors that affect signal availability influence coverage.

##### Time and Frequency

*Frequency Accuracy:*  Maximum long-term deviation from the definition of the second without external calibration. This is measured as the frequency difference from a recognized and maintained source.[[6]](#footnote-6)

*Frequency Stability:* Change in frequency over a given time interval.

*Timing Accuracy:*  Absolute offset in time from a recognized and maintained time source of UTC[[7]](#footnote-7)

##### Performance Parameters Interrelationship[[8]](#footnote-8)

In many instances, the characteristics of the eLoran system affect all or some of the performance parameters (e.g., the signal-to-noise ratio [SNR] affects accuracy and integrity). Also, a characteristic may affect different parameters in different ways (e.g., the number of stations available to determine a fix may improve accuracy but may reduce integrity). In addition, the impact of a performance parameter and system characteristic may differ from user community to user community. These interrelationships and other possible interrelationships among performance factors, system characteristics, and user applications are optimized to meet the application’s requirements for shipborne receivers.

##### Phase Factors

An eLoran receiver takes Time of Arrival (TOA) measurements of the Loran signals. For the purpose of positioning, the TOA measurement is converted to a pseudo range by multiplication with the speed of light (*c)*. Since the Loran signals propagate through air and over a conducting surface, the propagation speed is lower than the speed of light in vacuum. The Time of Arrival needs to be corrected to compensate for the delay due to lower propagation speed. Refer to Figure 3.3 for an illustration of the definitions below and their relationship. Appendix D also contains additional information on the various phase factors.

###### Primary Phase Factor

The primary phase factor (PF) accounts for the fact that the Loran signals propagate through the earth’s atmosphere as opposed to in free space (vacuum). The speed of light in atmosphere used is = 299691162 m/s which corresponds to an index of refraction of approximately 1.000338.

The lower propagation speed is compensated for by a primary factor delay in the TOA processing. This is incorporated in Equation 3.1 discussed next.

###### Secondary Phase Factor

The sea-water secondary phase factor (SF), reflects the fact that the Loran ground wave is further retarded when traveling over seawater as opposed to through the atmosphere. Equation 3.1 calculates the total Primary Factor and Secondary Factor phase delay *p* in meters[[9]](#footnote-9)

 Equation 3.1

where

*p* = phase delay in metres,

*S* = 10-5 times distance in metres,

*e* = base of natural logarithm = 2.71828,

*B*1..5 = coefficients for all-seawater path.

|  |
| --- |
| *B*1 = -111 |
| *B*2 = 98.20 |
| *B*3 = 13 |
| *B*4 = 113 |
| *B*5 = 0 |

In order to calculate the phase delay in seconds, *p* in Equation 3.1 needs to be divided by the speed of light in vacuum, *c* (299792458 m/s).

The user receiver compensates for Primary Factor and Secondary Factor delays using Equation 3.1.

###### Additional Secondary Phase Factor (nominal)

The Additional Secondary Phase Factor (ASF), accounts for the additional delay caused by signal propagation over land and elevated terrain when compared to the delay experienced over sea-water. Depending on the receiver’s location, signals from some eLoran transmitters may have traveled hundreds of kilometers over land and must be corrected to account for the additional delay imparted by the non-seawater portion of the signal path. An ASF is the cumulative delay the signal experiences when traveling over sections of land with different ground conductivity.

The eLoran service provider publishes ASFs for a geographic area of interest (e.g. a Harbor Entrance and Approach area). ASFs are published as a nominal ASF value and an ASF grid provides the difference from the nominal value as a function of geographic location within the grid for each eLoran station. The receiver determines the ASF value for its location by adding the nominal ASF value with the ASF grid value for its location.

ASF = ASFnominal + ASFgrid Equation 3.2

The eLoran service provider shall use Equation 3.1 in generating the nominal ASF and ASF grid values for publication. The user receiver shall use equation 3.1 to compensate for PF and SF delays in addition to the ASF delay. ASFs are provided in microseconds. Even with the corrections, there are still residual errors. The difference in ASF between locations does vary slightly thus resulting in some errors from the constant difference grid.

Should the eLoran service provider offer ASF measurement error bound data, this should be employed by the receiver manufacturer in the computation of HPL.

A recommended service provider ASF data format is presented in Appendix D.

###### Differential-Loran Corrections

In order to provide the highest possible eLoran accuracy, the maritime service provider installs a differential-Loran (DLoran) Reference Station in a static location close to the area of interest. This Reference Station calculates differential-Loran corrections and broadcasts them through the Loran Data Channel of one or more eLoran transmitters within range. The differential correction compensates for any temporal variations in Primary Factor, Secondary Factor and Additionally Secondary Factor delays, as well as possible errors in transmitter UTC synchronisation. Differential-Loran corrections are provided in units of microseconds. The difference between the location of the differential Reference Station and the location of the user equipment can result in errors.

The differential data format is presented in Appendix B.

###### Time of Arrival Processing

The received Time of Arrival of an eLoran station converts to a pseudo-range measurement according to Equation 3.3

PR = TOA\**c* - *p* – (ASF + δ)\*1e6\**c* Equation 3.3

where

PR = Pseudo range in meters

TOA = Time of Arrival in seconds

*c =* speed of light in vacuum

*p* = phase delay in metres (equation 3.1); PF+SF

ASF= published ASF in microseconds (equation 3.2)

δ= differential eLoran corrections in microseconds,

Phase Factor Relationship

Figure 3.3. Components and factors affecting measured time of arrival using alternative definition of PF.

##### Standard Zero Crossing

Referring to Figure 3.2 the Standard Zero Crossing (SZC) is the positive zero crossing at the point 30 microseconds into a positively phase coded pulse on the antenna-current waveform. This zero crossing is phase-locked to the eLoran station’s cesium time reference. The standard zero crossing is used as a timing reference for measurement of eLoran signal specifications.

##### Envelope to Cycle Difference

The Envelope to Cycle Difference (ECD) has both a near-field value as well as a far-field value. The difference is that one is measured at the ground return on the base of the transmitting antenna and the other determined at the user location. See Figure 3.4.

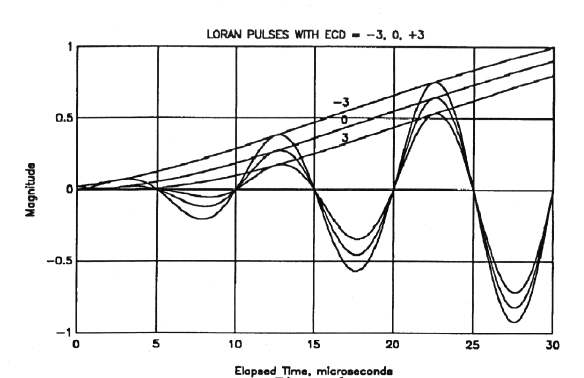


Figure 3.4 eLoran pulses with ECD’s of -3, 0 and +3 microseconds

###### Envelope to Cycle Difference at the Transmitter

This effective shift in time position of the envelope ahead or behind the standard sampling point (at the transmitter) is known as Envelope-to Cycle Difference (ECD).

###### 

###### Far-field Envelope to Cycle Difference

Conceptually, the leading envelope of a local radio frequency (RF) field will be fit to the same ideal eLoran envelope equation with a similar cost function as used in the transmitter antenna current algorithm. In the actual receiver, the RF signal is digitized after the signal has been processed by some known frequency response. The eLoran receiver must determine the far-field ECD for each signal and calibrate this measurement so that it matches the standard ECD measurement as seen Figure 3.4. Whatever algorithm is used at this point, the receiver’s algorithm must give the same answer as would have been obtained if the local RF field had been available.

*Note: There are two methods for calibrating the algorithm:*

*1. Software simulation where pulses of various ECDs and phase modulation conditions are filtered by a model of the RF front end and the user receiver ECD algorithm calculation is compared to the model.*

*2. Hardware simulation where pulses of various ECDs and phase modulation conditions are generated and used as input to the receiver.*

##### Time of Arrival

The time of arrival of the pulse group from a transmitting station is the time of occurrence of the electric field of the standard zero crossing of the 1st pulse, in a pulse group at the receiving antenna, with respect to the local receiver clock.

##### Nominal Antenna

The nominal antenna for a receiver shall be specified by the manufacturer. In carrying out the specific test procedures, the signal levels at the space coupling node shall be related to the field strength in proportion to the effective height of the nominal antenna.

##### Blink

An indication of out-of-tolerance (OOT) at a transmitting station will occur for one of the following reasons:

* Time of emission is out of tolerance
* ECD out of tolerance
* Improper phase code or GRI
* Master or secondary station operating at less than one half of specified output power

When an OOT situation exists, it is indicated by the OOT eLoran signal being turned off. If the signal is returned to a non-OOT condition before 10 seconds, then it returns on-air without any other indication. If it does not, it will stay off air for a minimum of 10 seconds and come back on air “blinking”[[10]](#footnote-10). Blink is a repetitive on-off pattern (approximately 0.25 second on, 3.75 seconds off) of the first two pulses of the secondary signal which indicates that the eLoran signal is unusable. Blink continues until the out-of-tolerance condition no longer exists.

##### Atmospheric Noise

In the low-frequency portion of the radio spectrum considerable atmospheric noise can be present. This noise is generated by the occurrence of lightning throughout the world. It has been well established that a background noise level representing the sum of distant storms and bursts from more local storms can characterize such noise. The international standards body, International Telecommunication Union- Radiocommunication Spectrum (ITU-R), has produced an extensive, empirically-based set of predictions of both these components. Receivers may use receiver non-linear processing algorithms that can detect, and can mitigate, the effects of the noise bursts (e.g., lightning).

##### Crossrate Interference

Each eLoran transmitter uses the same RF spectrum as all the others and they transmit at times that periodically conflict with one another. This means normal receiver frequency filters will “pass through” signals from neighboring GRIs whose time of arrival will cause them to occasionally overlap, and interfere with, signals from local stations. This is referred to as cross-rate interference (CRI) and it causes variations in signal measurements that effect alarm detection, cycle selection, and other calculations. Crossrate interference can be mitigated by processing techniques such as cancellation or blanking. Receivers may use different techniques to mitigate cross-rate interference.

##### Transmitter Blanking

An eLoran transmitter can operate in two chains with two GRIs (dual-rate). On regular intervals dual-rated stations may need to broadcast pulses on both rates at the same time. If this happens the eLoran transmitter gives priority to broadcast pulses of one of the rates and blanks the transmission of the pulses in the other rate. The eLoran service provider shall provide information on the blanking regime of each dual-rated transmitter (priority or alternate, partial blanking and guard times), so that the receiver may properly deal with blanked pulses.

##### Skywave

Skywaves (see Figure 3.5), in the context of eLoran, are reflections of the signal from the ionosphere. From the stand point of navigation, this signal is an interference source and cannot be used for precise navigation. The reflection can occur at different heights and strengths resulting in variations in the delay and received amplitude for a given location. For a given reflection height, the delay and strength relative to the groundwave is a function of the distance from the user to the transmission source.

Under nominal conditions, the night-time ionospheric environment results in a skywave that is stronger than in the daytime. The night-time ionosphere also tends to have a higher ionosphere reflection height for eLoran resulting in a greater delay relative to the groundwave than typical daytime skywave.

While always present, skywaves typically do not affect the eLoran position fix. Receivers shall be able to function under typical day time and night time occurrence of skywave.

“Early skywave” is skywave with delays of roughly 37 µsec or less relative to the ground wave. This skywave can be problematic as it is close to the tracking point of the groundwave. Early skywaves generally occur during the day time and are induced by severe solar weather activity. Under conditions of adverse solar weather, the ionosphere can be disturbed enough to lower the ionospheric reflection height and strengthen the reflection for the eLoran signal. This can create problems for signals traveling over long paths. Since the disturbed ionosphere is caused by solar activity, the reflection region must be illuminated by the sun. The effect is particularly strong at high geomagnetic latitudes.

The difficulty with early skywave versus typical skywave is that is more difficult for a receiver to disregard, mitigate or detect. For example, receivers on moving platforms may not be able to easily discern errors caused by early skywave from platform movement. Hence, the eLoran system requires some means to be aware of early skywave or its effects through monitoring.

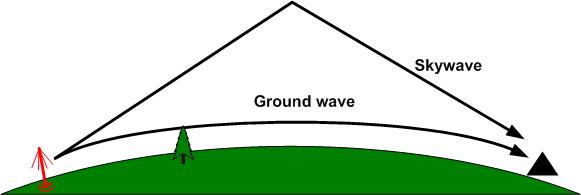


Figure 3.5 Skywave

###### Skywave Processing (user receiver)

The receiver has algorithms or processing that mitigates the presence of skywave in the local service error. It may exclude the use of signals with significant errors caused by skywave. Alternatively a receiver may dynamically adjust the location of the tracking point in the eLoran pulse to balance high signal strength (by tracking later in the pulse envelope) with skywave rejection (by tracking earlier).

###### Skywave Warning (service provider)

A skywave warning may be provided by service providers to indicate the possibility of a skywave in a specified geographic region and transmitted signal. The details of this warning shall be as specified by the service provider. See LORIPP/LORAPP Draft Specification of the eLoran System, Rev. 4.0[[11]](#footnote-11) for the eLoran System for further details. If provided, the warning shall be part of the transmitted LDC message.

##### Interference

Interference is a man-made source of radio frequency energy which has sufficient energy to adversely affect the performance of an eLoran receiver. Interference may be synchronous, near synchronous, or non-synchronous. Synchronous and near synchronous interfering signals of sufficient amplitude will cause increases in the mean error of the TOAs at the receiving set. Non-synchronous interfering signals will increase the standard deviation (jitter) of the receiver TOAs. Generally, eLoran receiving equipment is more sensitive to synchronous and near synchronous interfering signals because these signals are at carrier frequencies very near the “comb filter” frequency responses of the eLoran receiver (i.e. the eLoran spectral lines of stations in one chain). At these frequencies, interference will cause problems when its level is so great compared to the desired eLoran signals that it causes the signal tracking circuits in the receiver to operate improperly. The effects of high level signals whether synchronous or non-synchronous can usually be most easily reduced with notch filters.

* In-Band Interference - interference whose carrier frequency lies in the band 90-110 kHz.
* Near-Band Interference - interference whose carrier frequency lies in the frequency bands 70-90 kHz and 110-130 kHz.
* Out-of-Band Interference - interference whose carrier frequency lies in the frequency bands below 70 kHz or above 130 kHz.
* Synchronous Interference - near-band interference whose carrier frequency (fc) is determined by f c = N/2 GRI, where N = 1, 2, 3....
* Near-Synchronous Interference - near-band interference whose carrier frequency (fc) satisfies the relationship │fc − N/2GRI │ < fb where fb is the tracking bandwidth of the receiver (related to response time)

##### Continuous Wave Interference

Continuous wave interference (CWI) is interference from man made sources that are intentionally radiated in or near the eLoran band. It results in additional noise and interference on the eLoran signal. Throughout the world, in the bands 70 to 90 kHz and 110 to 130 kHz, there are broadcast stations which operate with keyed CW, modulated CW and FSK modulation schemes. Generally, no more than two interfering frequencies are transmitted from any one station at any one time. The radiated power may be as great as 100 KW. These interfering signals may adversely affect the eLoran receiver performance simply due to their extremely high level.

##### Interference (other)

Man-made interference can also result from inadvertent transmissions from human activities. Examples of such interference include power line carriers and emission from automobile engines.

##### Field Strength

Field Strength RMS value in volts per meter of the envelope at the standard zero crossing.

##### Signal to Noise Ratio

Signal to noise ratio (SNR) is the ratio of the root mean square (RMS) amplitude, of the envelope, of the eLoran pulse, at the standard zero crossing point, to the RMS value of the noise present at that time.

It is recognized that measuring signal and noise in the context of a receiver inherently requires some amount of processing. It is also recognized that this processing is not limited to, but may include different forms of signal averaging, and different amounts of filtering prior to a signal measurement or a noise measurement. It is also recognized that SNR measurements are heavily influenced by the design of the receive antenna, the analog front end, and a receiver’s digital filters. This document attempts to standardize the definition of SNR in an attempt to reduce the variability of reported SNR values, between various receivers.

With regard to an SNR measurement, signal level shall be normalized to a level equal to that of a single eLoran pulse.

With regard to an SNR measurement, noise level shall be measured at a point where there are no tracked eLoran stations, and any averaging that has been performed, must be accurately compensated for.

The noise measurement shall be taken after interference mitigation including, but not limited to CWI, impulse noise, crossrate mitigation, and notch filtering.

With regard to receiver filtering distorting the shape of the eLoran pulse envelope, SNR shall be reported in a manner after the description of ECD in section 3.1.2.10.1. That is, whatever filtering or processing is performed by the receiver, the SNR shall be equivalent to that of the local RF field at the sky-connection node, if such an observation were available. Calibration of SNR-reporting algorithms can be performed in the same way as for ECD.

#### 

#### APPENDIX C Abbreviations

Several abbreviations like the definitions are taken directly from the nominative references for ease in understanding this MPS and to avoid confusion.

* ASF: Additional phase Secondary factor
* CWI Continuous Wave Interference
* ECD: Envelope to Cycle Difference
* eLoran: Enhanced Loran
* EUT: Equipment under test
* TD Time Difference
* TOA: Time of Arrival
* COG: Course over Ground
* GPS: Global Positioning System
* GNSS: Global Navigation Satellite System
* GRI: Group Repetition Interval
* HEA Harbor Entrance and Approach
* HDOP Horizontal Dilution Of Precision
* HMI Hazardously Misleading Information
* HPL: Horizontal Protection Limit
* HSC High Speed Craft
* PCI Phase Code Interval
* PDOP: Position Dilution Of Precision
* PF: Primary phase Factor
* RAIM: Receiver Autonomous Integrity Monitor
* RMS Root Mean Square
* SDME: Speed and Distance Measuring Equipment
* SF: Secondary phase Factor
* SNR Signal to Noise Ratio
* SOG: Speed Over Ground
* SGR: Skywave to Groundwave Ratio
* SIR: Signal to Interference Ratio
* TTFF: Time To First Fix
* USNO: United States Naval Observatory
* UTC: Universal Time Coordinated
* 2drms twice distance root mean square.

# 

# APPENDIX D Receiver Algortithms

## D.1 ASF calculation

 (D1.1)

where

*TOAMeasured* = Time of Arrival measurement to one station

*PF* = Primary Factor, the propagation time of the signal through the atmosphere

*SF* = Secondary Factor, the difference between propagation over an all-seawater path and propagation through the atmosphere,

*ASF* = Additional Secondary Factor, the difference between propagation over land and elevated terrain, and propagation over an all-seawater path,

*TReceiver Error* = Receiver clock error with respect to eLoran system time,

*TTransmitter Error* = Transmitter clock error with respect to eLoran system time,

*TNoise* = Timing error due to noise and residual continuous wave and cross rate interference,

*TOAc* = Time of Arrival of the signal from the station under the assumption of propagation with the speed of light, *c*,

Δ*PF* = Delta Primary Factor, the difference in propagation time between propagation through the atmosphere and free-space propagation.

Consequently:

 (D1.2)

Now, *PF* can be calculated using:

 (D1.3)

where

*Distance* = the great circle distance based on the geographic location found by (D)GPS and the transmitter location, for this we use Sodano’s method,

*Vatmosphere* = propagation speed of the signals through the atmosphere,

*ηatmosphere* = the refractive index of the atmosphere taken at the surface of the earth, 1.000338,

*c* = the speed of light (299792458 m/s).

Δ*PF* can be calculated using:

 (D1.4)

In order to calculate the Secondary Factor, *SF*, we make use of Brunavs’ equations **Error! Reference source not found.**. These equations give the delay of a 100-kHz signal travelling in the atmosphere over the earth as compared to free-space propagation. This way the Brunavs equations calculate the contribution of Δ*PF* + *SF*, in case the equations are set up for an all-seawater path.

Two equations are derived from the Brunavs tables:

Formula B:

 (D1.5)

Formula C:

 (D1.6)

where

*p* = phase lag in metres,

*S* = 10-5 times distance in metres,

*e* = base of natural logarithm = 2.71828,

*B*1..5 & *C*1..8 = coefficients dependent on ground conductivity.

For an all-seawater path the B and C coefficients are:

|  |  |  |
| --- | --- | --- |
| *B*1 = -111 |  | *C*1 = -111 |
| *B*2 = 98.20 |  | *C*2 = 98.20 |
| *B*3 = 13 |  | *C*3 = -13.51 |
| *B*4 = 113 |  | *C*4 = 112.8 |
| *B*5 = 0 |  | *C*5 = -0.254 |
|  |  | *C*6..8 = 0 |

In order to calculate the phase lag in seconds, p in equation 5 and 6 needs to be divided by the speed of light, *c*.

Equation 6 is expected to be more accurate at longer distances than Equation 5.

The Secondary Factor, *SF*, can now be found:

 (D1.7)

with

*p* = delay in meters as calculated by Brunavs Equation 5 or 6 for an all-seawater path,

Δ*PF* = Delta Primary Factor as calculated in Equation 4.

## D.2 RTCM SC-127 ASF Data Format

ASF data will need to be provided to the mariner by the service provider. It is recommended that the ASF publishing authority provides ASF data in RTCM SC-127 format as outlined below. However, it is recognized that other formats may be available for data dissemination.

In SC-127 format data is presented in text files as data grids, with a number of lines of preamble and metadata. In general the data shall have the following characteristics:

* There shall be one file per coverage area (a ‘coverage area’ shall be a port approach, or other region specified by the service provider)
* The file shall be in ASCII format
* Data fields shall be Comma Separated Values (CSV)
* Geographical co-ordinates shall be specified as degrees and decimal fractions of degrees, e.g. 51.2°N; co-ordinates west of Greenwich or south of the Equator shall be specified as negative numbers
* Geographical co-ordinates shall be specified to a precision of up to 4 decimal places
* Leading or trailing zeros (0) shall be used where appropriate to allow uniform formatting
* For parity check purposes the last entry on a line shall contain a Cyclic Redundancy Check CRC-16 in four digit hexadecimal notation of the preceding data in the line, including the ‘,’ separator character. This CRC-16 value shall have ‘\*’ pre-pended to it
* The end of the data file shall be indicated using the string ‘#END’

The information provided for each coverage area shall include the following in order:

* RTCM SC identifier and reference to Minimum Performance Specification version conformance
* The name of the coverage area
* Name of issuing organisation, Issue number of the data, and date of issue in YYYY,MM,DD format
* The boundaries of the area covered by the enclosed grid of data (N/S/E/W)
* The number of cells in the grid (height, width)
* The name of the associated differential-Loran (DLoran) reference station; the ID number of the DLoran reference station; the number of separate eLoran signals for which ASF data is provided (and for which DLoran corrections are transmitted)
* The name, GRI and letter designator of the eLoran transmitter, and its designation in the Eurofix DLoran correction message format transmitted from the DLoran reference station
* The data type (#ASF or #ERR) of the following data
* ASF values shall then appear as CSV in Lexicographic Format (W to E, N to S) in microseconds to three decimal places
* ASF measurement error values shall then appear as CSV in Lexicographic Format (W to E, N to S) in meters to two decimal places. Error values are given as standard-deviations and are provided to allow the calculation of Horizontal Protection Level (HPL).

The above format shall be repeated in order for each monitor site and eLoran station combination in each coverage area.

Example (*Not to be used for navigation!*)

RTCM SC-127,V2.0\*0x8888

Dover\_Straits\_North\*0x1742

Issue,GLA,V1.2,2013,01,25\*0x6195

51.1000, 51.2080, 001.1000, 001.3580\*0x3640

24,36\*0x1A04

#REF,Dover,101,6\*0xA1A5

#TRX,Anthorn,6731,Y,2\*0x78E0

#ASF,\*0x9CC9

2.412, 2.456, 2.123, 2.431,…………………… 3.124\*0x4517

2.478, 2.788, 2.112, 2.346,…………………… 3.042\*0x6767

.

.

.

3.478, 3.757, 3.141, 3.336,…………………… 3.192\*0x6767

#ERR\*0x2EA3

10.21, 04.41, 00.12, 00.12,…………………… 00.09\*0x4517

06.76, 01.01, 00.11, 00.04,…………………… 00.02\*0x6767

.

.

.

00.32, 00.45, 00.44, 00.03,…………………… 50.00\*0x6767

#TRX,Lessay,6731,M,0\*0xE5C4

#ASF\*0x9CC9

2.412, 2.456, 2.123, 2.431,…………………… 3.124\*0x4517

2.478, 2.788, 2.112, 2.346,…………………… 3.042\*0x6767

.

.

.

3.478, 3.757, 3.141, 3.336,…………………… 3.192\*0x6767

#ERR

…

#END

## D3. Interpolating ASF and ASF Measurement Error Data

ASF data is defined as point values located at the vertices of a regular lattice of cells between the geographical limits given.

It is recommended that receiver manufacturers implement a two-dimensional interpolation algorithm in order to provide a smooth transition when the mariner moves between ASF data cells. The following describes a suitable algorithm.

At a particular location, , given by the co‑ordinates , the geographical position of the receiver within the ASF grid cell can be expressed in terms of two parameters  and  (See Figure D.1); the longitudinal and latitudinal distances respectively into the cell from the southwest corner.

In computing the position solution, an initial location  may be an arbitrary seed position, or the previous computed eLoran position.

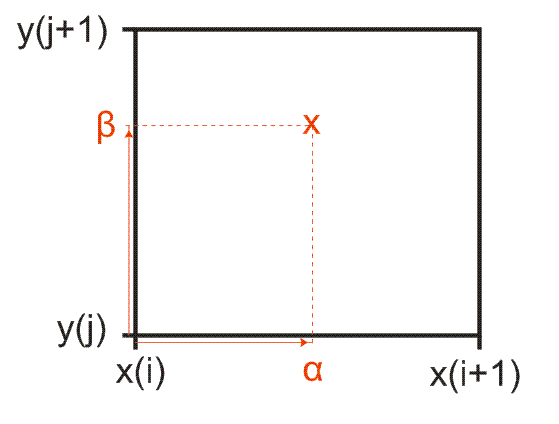


Figure D.1 – Interpolating between ASF data cells.

 (D.3.1)

 (D.3.2)

In equations D.2.1 and D.2.2  and  are the WGS84 co-ordinates (southwest corner) of the grid cell, within which the receiver is currently located. The earlier calculated parameters  are then used to perform a two dimensional interpolation between the four nearest grid elements  -  (Figure D.2):

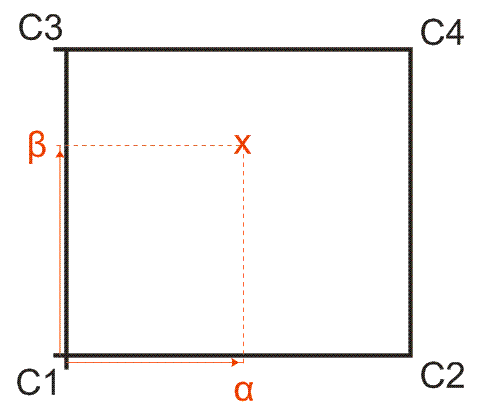


Figure D.2 – Four nearest grid elements.

The ASF value at location  is then given by the Interpolation Equation:

 (D.3.3)

ASF Measurement Error may be included as one of the components of an Integrity Equation for the computation of a Horizontal Protection Level (HPL). In this case the#ERR field data may be interpolated as follows:

 (D.3.4)

Please note that ASF Measurement Error is only one of several components of an HPL computation.

## D.4 Integrity Algorithm

At a minimum, receiver manufacturers are required to implement the following Integrity checking algorithm. Some aspects of this integrity algorithm require a certain level of support by service providers.

Position Integrity is provided in three steps:

* + 1. Verify signal-tracking
    2. Check Integrity of Fault-Detection
    3. Calculate Horizontal Protection Level (HPL)

These are now each described below.

**Step 1 – Signal Tracking Integrity**

The pseudo-range equation is defined as:

 (D4.1)

PF and SF are calculated for an Assumed Position (AP), ASF is extracted from the relevent ASF Map at the AP, and DL is the latest Differential-Loran correction received for that signal. Position-fixing continues as an iterated update to the AP by weighted least-squares, changes to pseudo-range are related to changes in geographic location by local linearisation:

 (D4.2)

 (D4.3)

α is the transmitter bearing (from true North) as given by the Vincenty algorithm.

The vector of position updates is:

 (D4.4)

Position updates for the AP iteration are given by Least Squares:

 (D4.5)

This iteration continues until the position updates are sufficiently small (|x|<1mm, or to within the precision of the geodetic distance calculation algorithm). W is the ‘ideal’ transmitter weighting matrix. We make the assumption that the receiver is able to estimate W as a reasonable approximation to the inverse of the pseudo-range covariance matrix:

 (D4.6)

The pseudorange residuals are given as the difference between the observed and estimated pseudo-ranges:

 (D4.7)

 (D4.8)

 (D4.9)

Define K and A as:

 (D4.10)

 (D4.11)

 (D4.12)

 (D4.13)

The test-statistic is a weighted sum-square of residuals:

 (D4.14)

is the receiver’s estimate of the residuals covariance matrix. Defining M as:

 (D4.15)

 (D4.16)

Where ε is the vector of errors on the pseudo-range measurements. Assuming each measurement is free of any gross errors or biases, it can be shown that WSSE is chi-squared distributed with n-3 degrees of freedom (n is the number of individual eLoran signals used in positioning). Any biases in pseudorange observation will alter the PDF of y to a (assumed) non-zero-mean Gaussian with means given by the vector μ. This results in WSSE taking a non-central chi-squared distribution with mean (non-centrality parameter) given by:

 (D4.17)

Example PDFs for WSSE in the faulted (zero-mean PR) and in the faulted cases are shown in Figure D4.1:

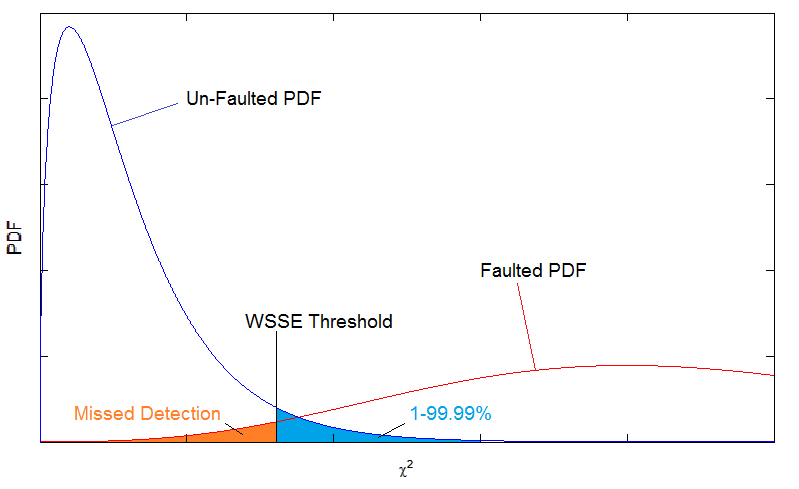


Figure D.1 – WSSE PDFs for un-faulted (Chi-Squared) and faulted (non-central Chi-Squared) pseudorange observations

We define a threshold value based on Probabilty of False Alarm (PFA) of 0.01%. If WSSE is above this limit we assume an error has occured in one of the PR observations and the user is alerted within 10 seconds. If it is below this then all PR values are accepted, pending the verification of the fault-detection algorithm (Step 2). If an error is detected, it may be possible to identify which measurement is faulted by rejecting the observations one-by-one, re-computing the AP and re-testing the residuals, this is Fault Detection with Exclusion (FDE).

**Step 2 – Check Fault-Detection Integrity**

To be sure that our Test-Statistic is a reliable method of locating faults, we must also ensure the Integrity of our test. This is done by calculating the Probability of Missed Deteciton (PMD) on the faulted PDF as shown in Figure D4.1. We have to be sure that, for any fault large enough to cause a hazardously inaccurate position-fix (accuracy > HAL), the PMD must be sufficiently low to provide the required Integrity.

This is done in several steps:

1. The amount of PR error needed on each signal to push the position-fix beyond the HAL is found
2. The Faulted PDF (as shown in Figure D4.1) for this case is integrated from zero to the Threshold value to give PMD
3. The probability of this fault actually occuring is calculated to give PErr
4. The Integrity of the monitor is found by summing across all possible combinations of PR faults

If the probability of Hazardously Misleading Information is calculated to be below the Integrity Level for the application, then the fault-detection algorithm is said to have ‘passed’ and we proceed to Step 3.

For each eLoran signal in turn, the amount of PR error needed for hazardous position-fixing is found using the K matrix:

 (D4.18)

The root-sum-square of the first two rows of K indicate how much position-bias is introduced for every meter of pseudorange error. By dividing the HAL by this we get an accuracy-limit on each pseudorange. This is the amount of error which (independent of any other pseudorange error or bias) would push the solution beyond the HAL, so is unacceptable in and of itself.

 (D4.19)

The vector of PR biases (μ) is given as being identically zero, with the ith entry equal to . The non-centrality parameter of the faulted case is given by (D4.17).

We find PMD by integration:

 (D4.20)

Χ2(n,m) is the non-central Chi-Squared distribution with n degrees of freedom and non-centrality parameter m. Its integral is given as an infinite sum of regular Chi-Squared variables.

 (D4.21)

This can be approximated by summing over only the first few dozen values of i, as the denominator factorial i makes sucessive terms in the sum tend to zero very rapidly once i is greater than λ/2. The chi-squared integral is given in terms of Gamma Functions and also rapidly approches zero as i increases.

 (D4.22)

Numerical methods exist for approximating complete and incomplete Gamma Functions. Alternatively pre-computed look-up tables of regular and non-central chi-squared integrals can be used.

To calculate the probability of the fault occuring we need a model of PR error due to all possible sources of error, noise and interference. A working model for this assumes pseudo-ranging is a zero-mean Gaussian with standard-deviation equal to the RSS addition of variances due to: transmitter jitter, carrier-phase noise; ASF measurement error; DLoran correction error; CRI / CWI noise; un-mitigated CRI / CWI bias and other sources of error.

We define the PR-variance as:

 (D4.23)

 (D4.24)

 (D4.25)

 (D4.26)

 (D4.27)

A working model of Perr is:

 (D4.28)

N(s) is a normal-distribution (Gaussian) with standard-deviation σPR. The correction factor 0.9999 accounts for the observed issue that a Gaussian PDF fails to bound true eLoran pseudo-ranging beyond four-nines, so we make to conservative assumption that *any* level of error can occur with at least 0.01% probability.

The above process, equations (D4.18) through to (D4.28), should establish PMD and PErr for the particular transmitter in question. This is repeated for each transmitter used in the position solution. The Integrity of the WSSE check is given as one minus the probability that, *any* of these errors occur and go undetected:

 (D4.29)

If this is lower than the Integrity Risk Level, then Step 2 is ‘passed’ and the receiver moves on to Step 3:

**Step 3 – HPL Calculation**

The HPL is found by propagating the pseudo-range variances given in (D4.27) through the position solution. Recalling Equation (D4.5), and the observation that the signal weighting should approximate the inverse of the pseudo-ranging covariance we derive the position-fixing covariance:

 (D4.30)

The HPL is given as a 3.3931\*DRMS bound derived from :

 (D4.31)

# APPENDIX E List of stations and GRI

The following table lists the eLoran/Loran stations along with their GRI

XXX Table to be added XXX

APPENDIX F – Differential e-Loran modulation



Time of Emission (TOE) of the eLoran signal from a station is defined as the start of the first pulse of a pulse group.

Emission Delay (ED) is defined as the difference between the master station’s TOE and the secondary station’s TOE in the same Group Repetition Interval (GRI). The definition of ED implies that the standard deviation of ED is a measure of how well a secondary station is time synchronised.

1. For high speed craft purposes the EUT has to provide an IEC 61162-2 interface with a position update rate of 2Hz. [↑](#footnote-ref-1)
2. Refer to regional specific signal specification for type of the envisioned communication scheme [↑](#footnote-ref-2)
3. Changes in almanac information (e.g., Station location) will be accomplished so that it will not create an HMI situation. [↑](#footnote-ref-3)
4. Changes in almanac information (e.g., Station location) will be accomplished so that it will not create an HMI situation [↑](#footnote-ref-4)
5. *Loran's Capability to Mitigate the Impact of a GPS Outage on GPS Position, Navigation, and Time Applications*; Prepared for the Federal Aviation Administration, Vice President for Technical Operations, Navigation Services Directorate; dated March 2004 [↑](#footnote-ref-5)
6. For example, these sources could be the U.S. Naval Observatory (USNO), National Institute Standard and Technology (NIST), or Bureau International des Poids et Mesures(BIPM). *UTC.* The international atomic time at based on cesium-133 with leap seconds added for variable earth rotation. [↑](#footnote-ref-6)
7. For example, these sources could be the U.S. Naval Observatory (USNO), National Institute Standard and Technology (NIST), or Bureau International des Poids et Mesures(BIPM). *UTC.* The international atomic time is based on cesium-133 with leap seconds added for variable earth rotation. [↑](#footnote-ref-7)
8. Same as footnote 1 [↑](#footnote-ref-8)
9. “Phase Lags of 100 kHz Radiofrequency Ground Wave and Approximate Formulas for Computation”, P. Brunavs, Contract Report, Canadian Hydrographic Service, March 1977. [↑](#footnote-ref-9)
10. Blinking is the method that is used to indicate that the Loran-C and eLoran signals are out-of-tolerance. [↑](#footnote-ref-10)
11. This system has yet to be developed [↑](#footnote-ref-11)