# Far East Radio-navigation Service (FERNS) Update

*S.G. Gug*, T. Ikeda**, P. Williams***, T.G. Jeong*****

** Korea Maritime University /FERNS/ Research & Radionavigation, the General Lighthouse Authorities of the United Kingdom and Ireland*
*** Japan Aids to Navigation Association*
**** Research & Radionavigation, the General Lighthouse Authorities of the United Kingdom and Ireland*
***** Korea Maritime University*

## Biography

**Prof. Dr. Seung Gi GUG** is an Associate Professor of the Department of Maritime Police Science at the Korea Maritime University where his main areas of research are Maritime Safety relating to Aids to Navigation/Waterway Design, and the Marine Environment related to the work of the Korean Government. In March 2008 he began work at the General Lighthouse Authorities' Research & Radionavigation Directorate on a year-long professional sabbatical where he has been investigating the benefits that enhanced Loran (eLoran) can bring to the Far East Radionavigation Service. He received the degrees of BSc and MA from the Korean Maritime University, and the degree of PhD from the Kyushu University in Japan. He is a board member of the Korean Institute of Navigation and Port Research, the Korean Aids to Navigation Association and is the Technical Chairman of FERNS.

**Mr. Tamotsu Ikeda** has been a member of Japan Aids to Navigation Association after his retirement from the director of communication division, visual aids to navigation division and radio aids to navigation division, Japan Coast Guard. He received the degrees of BSc and MA from Waseda University. He had participated and contributed to the meetings of IMO, COSPASS-SARSAT, and IALA etc. He managed the ODA projects 2000 for Indonesian Communication and Aids to Navigation and chaired the ILA 33rd annual convention and the technical symposium in Tokyo, 2004.

**Dr. Paul Williams** is a Principal Engineer with the Research and Radionavigation Directorate of The General Lighthouse Authorities of the UK and Ireland, based at Trinity House in Harwich, England. As the technical lead of the GLA's eLoran Work Programme, he is involved in planning the GLAs' maritime eLoran trials and works on a wide range of projects from real-time differential-Loran system development to the quality assurance of Loran ASF data. He holds BSc and PhD degrees in Electronic Engineering from the University of Wales, is a Chartered Engineer, an Associate Fellow of the Royal Institute of Navigation and is a board member of the International Loran Association.

**Tae-Gweon JEONG**, PhD & Capt., Professor of Navigation System Engineering Division, joined the faculty of Korea Maritime University in 1993. He holds BS (1977), MS (1979) and PhD (1990) degrees in Electronic Navigation from the Korea Maritime University. His research interests include electronic navigation system, evaluation of bridge simulator and its application. He is currently involved in research projects developing a new collision avoidance system by expert system and a positioning system by using free gyros. He is a member of professional organizations, i.e., secretary general of the Korean Institute of Navigation and Port Research, and members of the Society of Maritime Safety and the Society of Naval Architects of Korea.

## Abstract

This FERNS update contains the latest issues and annual activities for Loran and Chayka programmes, operational and technical matters for the cooperating chains and radio navigation services in the Far East. The first session of the Technical Working Group was held in the Sanbancho Meeting Room, Tokyo Japan, during the period of 27th February – 1st March 2007. At this meeting, substantial discussions took place concerning technical matters of Radionavigation systems in the Far East Region.

The Sixteenth Session of the Council (FERNS 16) was held in Muta Kyoyo Kaigisho Conference Centre, Tokyo Japan, during the period 29 October – 2 November 2007. The venue of the Council followed the second session of the FERNS Technical Working Group to develop regional co-operation between neighbouring countries not only on Loran/Chyaka but also on AIS, DGNSS and even on VTS. The Seventeenth Session of the Council (FERNS 17) will be held in Moscow,

on 10th – 14th November 2008, and this meeting will include a meeting of the Technical Working Group. It has been realised that the current FERNS chains may not be sufficient to meet the requirements for backup and complement of GNSS, unless their performance is improved. The research presented in this paper is aimed at verifying the needs for improving the FERNS chains; as such, the accuracy and functioning of the chains was analyzed. Plans to improve the chains including a brief outline of the system requirements are also included.

**Keywords**: *FERNS (Far East Radio Navigation Service), Loran-c/Chayaka, Coverage, Performance, System requirement, eLoran*

## 1. Introduction

In 2000, People's Republic of China, Japan, Republic of Korea and Russian Federation came to the FERNS (Far East Radio Navigation) agreement on an international program for the establishment of a joint radionavigation service in Far Eastern Waters. The importance of the joint use of "Loran-C" and "Chayka" systems was noted, and it was desired to strengthen and broaden international cooperation to ensure safe navigation in the interests of users from all the involved States. There are 6 Loran stations in China, 4 stations in Japan, 2 stations in Korea and 4 stations in Russia. With the exception of a single Russian station, they have radiated robust Loran/Chayka signals for a number of years. The old hyperbolic Loran-C system delivered a positioning accuracy of 460m, principally to mariners sailing in coastal and oceanic waters. When the Global Navigation Satellite System (GNSS) appeared in the 1980s, with its positioning accuracy of tens of meters, many began to regard Loran-C as irrelevant. The users of Loran-C/Chayka have also migrated to GNSS and there are few users left. However, others saw Loran as an essential source of position and time that could still be relied upon if GNSS failed.

But the performance of the FERNS chains may not be good enough to meet the requirements to backup and complement GNSS, unless improved upon.

In this paper, firstly the latest issues and annual activities in the Far East are reported. Then the accuracy and functioning of the FERNS chains were analyzed in order to verify the need for improving them. Plans to improve them include the development of system requirements.

## 2. Latest Meetings

### 2.1 Technical Working Group

The first session of the FERNS Technical Working Group (TWG) was held in Tokyo, Japan, during the period of 27 February to 1 March 2007. The report of the 1st session addressed the actions so far taken and the future intentions on the following topics:

- A working program for the next three year period (2007 – 2009)
- Improvement programs for FERNS Cooperating Chains
- Mutual interference between DGNSS stations
- Information exchange on future plans of DGNSS in FERNS members
- Information on types of Loran-C/Chayka and other integrated user equipment
- Practical use of AIS in the AtoN field
- Program, policy and technical issues developed by the USCG
- Technical matters on eLoran and e-Navigation.

The second session of the FERNS TWG was also held in Tokyo on 29 October 2007. It contained the finalization of the work on the Terms of Reference for approbation by the Council and a revision of the FERNS TWG Working Program and of the Action Plan.

### 2.2 The Sixteenth Session the council (FERNS 16)

The Sixteenth Session of the Council FERNS(16) was held in Mita Kyoyo Kaigisho Conference Centre, Tokyo, Japan, during the period 29 October – 2 November 2007.

According to the agenda, each country reported on operational and technical matters concerning Loran-C/Chayka. A brief outline of the activities follows:

1) Presentation of a Report by Each Country on the Loran-C/Chayka Programme:
    - Chayka/Loran-C/Chayka-SNS/Eurofix /DGNSS integrated receivers; Russia informed the Council members that the development of Chayka/Loran-C/Chayka-CNS/Eurofix/DGNSS integrated receivers is completed and that tests are ongoing. They concluded that the general trend is to evolve towards a kind of eChayka system by analogy to the eLoran system.

- Report of the *Ad-Hoc* Meeting on Loran/Chayka. The observer from Norway reported on the IALA *Ad-Hoc* Meeting on Loran/Chayka held in Haugesund, Norway, during the period 24 – 25 September 2007.

2) Report of FERNS Technical Working Group (FERNS TWG) (2.1)

3) Operational matters for FERNS cooperating chains

- Operational Matters; each country reported on their chain operational status during the last past year.
- Timing functions; China indicated that they start to introduce new components and highly integrated circuits which will be able to perform the functions of the existing equipment, but also EUROFIX like transmissions and timing functions.
- Scheduled off-air in 2008; Information concerning the proposed Off-Air schedule for 2008 was provided by each country.
- Revision of FERNS Operating Guidelines

4) Technical matters for FERNS cooperating chains

- Integrated GLONASS/GPS/Loran C/Chayka receiver; Russia, reported on new integrated user equipment development and gave information on the development and production of an integrated GLONASS /GPS/Loran C/Chayka receiver.
- Proposal for common research for Enhanced Loran; Korea made a proposal for common research and establishment of cooperation for Enhanced Loran. Therefore, to make preparation for the e-Loran system, Korea suggested that FERNS Members should cooperate together by researching technical matters in common and by exchanging the materials as follows:
    - The agreement on the application of a technical method and the allocation of the measurement areas for each station for the production of the Far East area ASF map.
    - The sharing of information and agreement related to transmitting messages using the undefined Loran Data Channel (LDC) type 4~14 messages.
    - The sharing of information for rearranging stations of each country and the agreement of restructuring each chain to solve shadow areas.
    - Exchange of information on each country decision to adopt eLoran.
- Timing and Time of Arrival ASF measurement; China presented a document on Timing and Time of Arrival ASF measurement detailing the principles of timing by Loran-C, the causes of systematic errors and the different equipment. The conclusions of the study were presented as follows:
    - Precisely absolute TOT can be obtained with the method of common view.
    - TOT can be broadcast in a digital form.
    - The newly-developed Loran-C receiver, with digital timing signal processing, can directly output UTC.
    - ASF, which has a great impact on timing accuracy of Loran-C, can be automatically measured.
    - Timing capability supports Loran-C as a regional backup to PNT service of GNSS.

5) Coordination of other radionavigation services in the Far East.
Council Members explained that they are still achieving their AIS and VTS installations and they continue to test and experiment with their installations. They agreed to cooperate in the future to share and exchange AIS information for enforcing countermeasure capabilities against marine casualties and for promoting maritime traffic safety.
A full list of DGNSS stations in China, Japan, Korea and Russia, was provided.

6) Symposium on e-Navigation
A symposium on e-navigation was organised on Tuesday the 30th of October 2007 to which Council Members participated as part of the 16th session. The Symposium was organised by the Ocean Policy Research Foundation and the Japan Coast Guard.

7) Date and Venue of the 17th session

The 17th session of the Council will be convened in Russia, 10th to 14th November 2008.

## 3. Improving the FERNS Chains

### 3.1 Coverage and Accuracy Performance

In estimating the coverage of the original Loran-C chains, the effects of signal attenuation, atmospheric noise, carrier-wave interference (CWI), sky-wave propagation, the change of envelope-to-cycle difference (ECD) with range, transmitter timing uncertainty, and receiver operation mode and location were all taken into account.

In order to confirm the effective range of the existing chains, firstly, the predicted accuracy performance of the FERNS Korea chain (GRI 9930) was calculated and analyzed. Figure 1 shows the estimate limits of coverage of the FERNS Korea chain, based on the existing published Loran-C coverage prediction. It consists of one master station (M/Pohang) and 4 secondary stations (W/Kwangju, X/Gesashi, Y/Niijima and Z/Ussuriisk). Table 1 shows the chain information [2].


**Figure 1 - Estimate Limits of Coverage of 9930**

The Zulu station at Ussuriisk has been off air for a number of years. Russia has been attempting to change the Chayka signal into Loran-C. It is expected that on-air transmission from the station will be achieved in the not too distance future.

In order to estimate the potential eLoran accuracy performance of the existing chains, we employed Matlab software developed by the GLAs. The software draws on a databse of electrical ground conductivity developed from the World Atlas of Ground Conductivities published by ITU-R (CCIR), an extract of which showing South Korea is shown in Figure 2 [3].

| GRI | Station | Latitude / Longitude | Power in Kw |
|---|---|---|---|
| 9930 East Asia (Korea Chain) | | | |
| DR 8930 | Master/Pohang | 036° 11' 05.450" N<br>129° 20' 27.440" E | 150 |
| | Whiskey/Kwang Ju | 035° 02' 23.996" N<br>126° 32' 27.295" E | 50 |
| DR 8930 | Xray/Gesashi | 026° 36' 25.038" N<br>128° 08' 56.920" E | 1000 |
| DR 8930 | Yankee/Niijima | 034° 24' 11.943" N<br>139° 16' 19.473" E | 1000 |
| Off Air DR 7950 | Zulu/Ussuriisk | 044° 31' 59.702" N<br>131° 38' 23.403" E | 700 |

**Table 1 - Loran-C 9930 Chain Information**

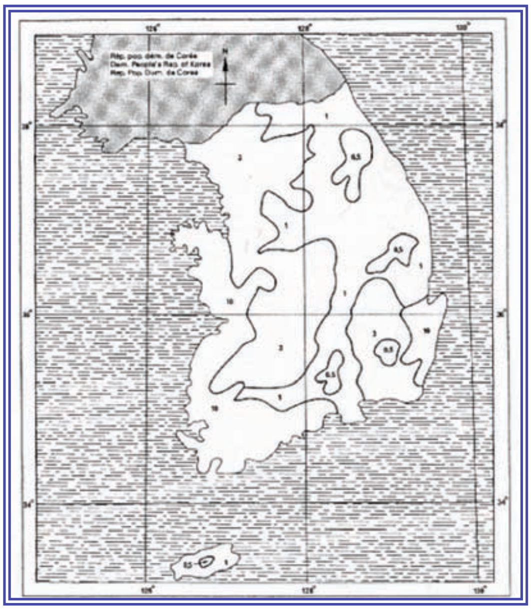


**Figure 2 - Ground Conductivity in South Korea**

The software also uses propagation curves and Millington's method to compute the field strength of each transmitter in the chain over its associated coverage area.

By using pseudorange measurements made at Harwich in the UK, it was possible to relate these field strength computations to the variances of the pseudoranges. An equation describing the relationship between the predicted field-strengths and pseudorange variation was then established. This technique was then extended for application in other geographical areas. The software also implements a repeatable accuracy computation based on weighted pseudoranges, in the same way that a Loran receiver will weight a transmitter's measurements in an eLoran all-in-view position solution. These weights were also computed from a relationship between modelled field-strength and the weights used by the receiver at Harwich.

In what follows the position accuracy predictions should be interpreted cautiously, since they are based on extending the measurements made in Harwich to the FERNS area. In the future it may be more appropriate to make separate measurements in FERNS.

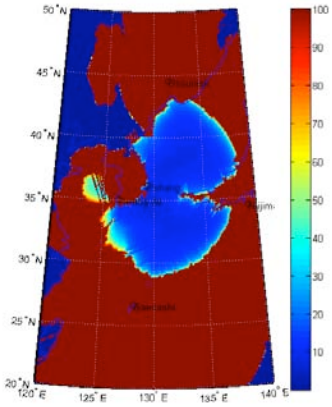
We proceed by analysing various configurations of stations in FERNS. First assuming all stations are available, and then taking into account the off-sir status of Ussuriisk. Note that these accuracy performance estimates assume that ASFs have been measured and are available within the users' receivers – this ensures that the highest *absolute* accuracy is achieved. The accuracy plots in the following show *repeatable* accuracy performance, and assumes perfect ASFs.

### 3.2 All Stations Available

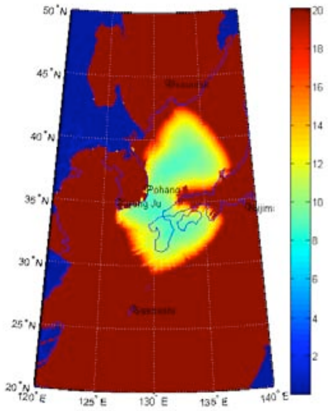
The accuracy performance calculations of the chain were carried out to verify the estimated accuracy limit on the assumption that the Ussuriisk Station is on-air and ASF measurements, which affect *absolute* accuracy, have been performed. Figure 3a shows the predicted repeatable accuracy within 100m (95%) and (b) within 20m (95%).

From Figure 3 we can see that the performance of the chain in the eastern and southern part of the Korean peninsular is quite good, but the performance in the western part is poor.

Figure 4 shows the distribution of the *measured* positioning performance of the chain over the last 2 years as measured by M/V "Hanvit". This vessel has been conducting measurements and evaluations for aids to navigation in and around South Korean waters since 2000.



(a) Accuracy within 100m (95%)



(b) Accuracy within 20m (95%)

**Figure 3 - Calculated Result in FERNS Korea Chain (all on-air)**

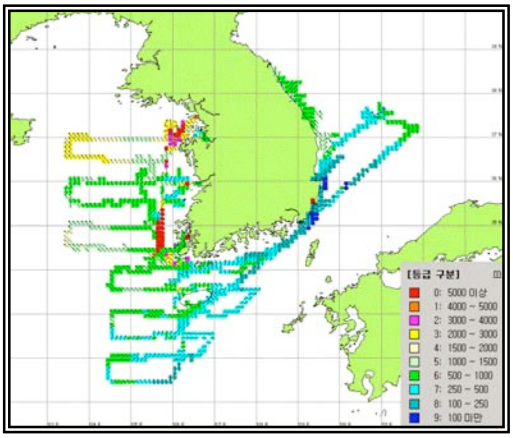



**Figure 4 - Measured Position Distributions of Korea Loran-C Chain**

There is a difference between the measured values of Figure 4 and the predicted values of Figure 3. The differences between the measured and predicted accuracy values may be caused by the fact that the measurements did not include perfect ASFs. It needs to use the measured data for the ASF correction and field strength.

From these results it is reasonable to conclude, however, that a new station in the western part of the peninsular of South Korea will be required in order to improve the performance of the chain.

### 3.3 Adding a New Station

It is proposed that a station, comparable in power to the station at Kwangju, be installed at a site in Kwangwhado about 50km northwest of Seoul. The site and specification for the proposed new station is shown in Figure 5 and Table 2 respectively.

There are several practical considerations including economical and political aspects that must be taken into account in choosing the site of a new station. In this paper, only the technical aspects were taken into account.

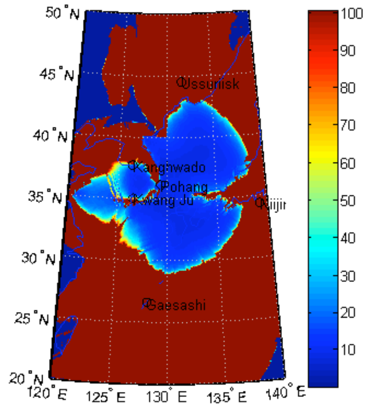

**Figure 5 - Proposed New Station in FERNS Korea Chain**

| GRI | Station | Lat/Long | Power in Kw |
|---|---|---|---|
| | Kwangwhado | About 037°.7N 126°.4E | 50 |

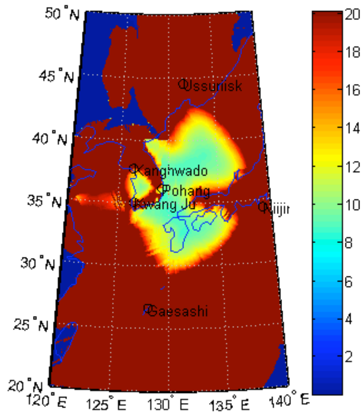
**Table 2 - Proposed New Station in FERNS Korea Chain**

The accuracy performance predictions of the chain including the proposed new station were carried out. We include the assumption that the Ussuriisk station is on-air and ASF corrections were measured for the new station. Figure 6a shows the accuracy performance prediction within 100m (95%) and (b) within 20m (95%). The results indicate that the performance of the chain in the western part of the peninsula will improve with the addition of the new station.

The results are very suggestive of the necessity for a new station to improve the chain and migrate to eLoran. In order to install a new station, further precise calculations based on measured data from the FERNS region may be needed. In addition, the user requirements and system requirements should be reflected upon.




(a) Accuracy within 100m (95%)



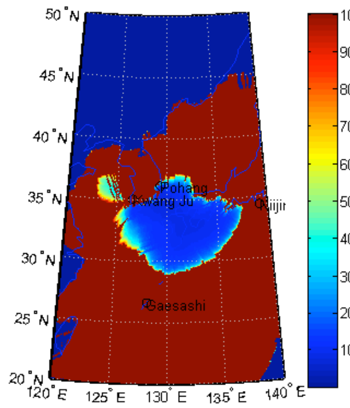

(b) Accuracy within 20m (95%)

**Figure 6 - Calculated Result in FERNS Korea Chain (Additional a new Station)**

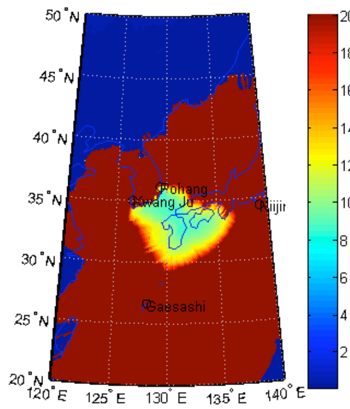
### 3.4 Considering Ussuriisk

At the moment, Ussuriisk, the Z station of the chain is off-air. Predicted accuracy performance calculations of the chain were carried out to verify the estimated accuracy coverage limit in case Ussuriisk is taken off-air permanently. Figure 7(a) shows the accuracy within 100m (95%) and (b) within 20m (95%).

The results indicate that the performances of the chain in southern and south-eastern part of Korean peninsular are quite good, but the performance in the western and north-eastern part of the peninsular are poor without this station.




(a) Accuracy within 100m (95%)




(b) Accuracy within 20m (95%)

**Figure 7 – Predicted accuracy performance in FERNS Korea Chain without Ussuriisk.**

### 3.5 An Additional New Station

The results so far are highly suggestive that FERNS should take steps to improve the existing Korea chain. This can be achieved by not only migrating the existing stations to eLoran, but also by adding new stations.

In addition to the proposed Kwanghwado station, another new station is proposed; one at the eastern end of the central peninsular.

In total then two new stations could be put under consideration with the same power as Kwangju. The sites and specifications for the proposed two new stations are shown in Figure 8 and Table 3.


**Figure 8 - Two new stations proposed in FERNS Korea Chain**

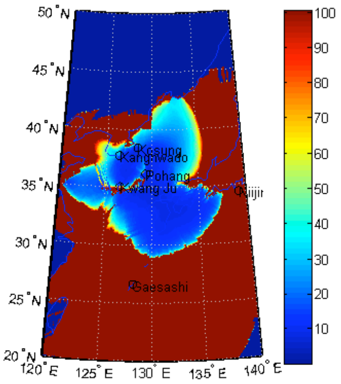
| GRI | Station | Lat/Long | Power in Kw |
|---|---|---|---|
| | Kwangwhado | About 037°.7N 126°.4E | 50 |
| | Goseong | About 038°.4N 128°.4E | 50 |

**Table 3 – Characteristics of the proposed new stations in the FERNS Korea Chain**

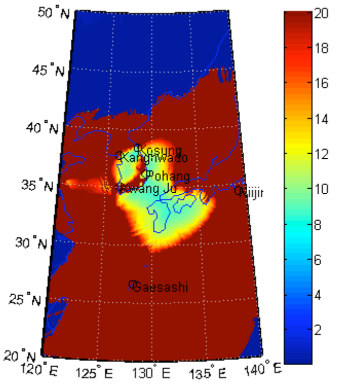
Again the predicted accuracy performance was analysed assuming the Ussuriisk Station is off-air. Figure 9 shows the predicted accuracy within 100m (95%) and (b) within 20m (95%). The results indicate that the performance of the chain in southern and south-eastern part of Korean peninsular are quite good, but the performances of it in the western and north-eastern part of the peninsular are poor.

The results are very suggestive of the necessity for at least two new stations to improve the chain and allow inland use, should Ussuriisk be permanently off-air.

This research will serve as a basis for future studies that will verify and improve the performance of all the FERNS chains. The research also indicates the importance of the station at Ussuriisk to the performance of the Korea chain.




(a) Accuracy within 100m (95%)




(b) Accuracy within 20m (95%)

**Figure 9 - Calculated Result in FERNS Korea Chain (Ussuriisk off-air + two new stations)**

In order to improve the chain, it must be possible to either establish an independent chain or co-operate with other chains.

In either case, it will be necessary to pay regard to the selection of Group Repetition Intervals (GRI) for new and existing stations [4].

## 4. System Requirements to Migrate Korea Chain to eLoran

In order to migrate the Korea chain to eLoran a modernized Loran infrastructure is required. This includes core service provision improvement in terms of the Accuracy, Availability, Integrity, and Continuity.

The system requirements for it are presented below and are based on [5].

Enhanced Loran (eLoran) when implemented achieves better Accuracy, improved Availability, System Integrity, and Continuity.

**<u>Better Accuracy</u>**
This is the degree of conformance between the measured position and the true position.

This is achieved by:

***1) Improved Timing and Frequency Equipment Capability***
***2) Improved Transmitted Pulse Characteristics***
***3) Using ASF Compensation***
***4) Conversion to Common View Loran Timing Monitors***

***1. Improved Timing & Frequency Equipment Capability***

- System utilizes three cesium clocks to compute a Local Timescale that is steered to UTC via UPS.
- Kalman filter models clocks and predicts clock performance when measurement data is not available.
- Three clock time scales provide Real-Time clock fault monitoring as well as superior stability.

***2. Improved Transmitted Pulse Characteristics***

As a result of redesigned Transmitter Control System (TCS) phase jitter is reduced by control of individual pulse versus group control.

TCS provides the capability for a robust envelope control (ECD) by dynamically reassigning power units (HCGS) during outage, due to failure of maintenance.

***3. ASF Compensation***

ASF correction data installed in the latest hybrid receivers maintains the absolute accuracy.

***4. SAM Conversion***

System Area Monitors are converted to Common View Loran Timing Monitors. Using the newly developed hybrid receivers as monitors adds to the accuracy.

**Improved Availability**

The ability of the system to provide usable service within a specified coverage. This is achieved by adding or converting to the following modern technology products.

1) ***Solid State Transmitter***
2) ***UPS System***
3) ***Improved Lightning Protection***
4) ***Switch to TOT Control***

1. ***Solid State Transmitter***
   At present, Solid State Transmitters are being installed at new stations or efforts are being carried out to replace the aging tube transmitters with Solid State Transmitters. In the last 5 years, efforts were carried out successfully to obtain higher power and better efficiency over the legacy Solid State Transmitters. In addition, certain modules, such as the power supply controllers were modified to achieve better and improved timing and amplitude stability. These developments have improved the availability of the Sold State Transmitters, which were already at greater than 99% availability.

2. ***UPS System***
   Adding a total UPS system to the Loran system which will support the transmitter operation, controls and monitors during power outage reduces the off-air time considerably.

3. ***Improved Lightning Protection***
   At regions were the stations are prone to higher lightning strikes, additional lightning protection at the base of the antenna reduces the damage to the equipment and the resulting off-air time. Also, lightning protection circuits were added to monitor and protect certain high power modules such as the tailbiters by electronically disabling them during lightning strikes.

4. ***Switch to TOT Control***
   Once all the stations in a chain are synchronized to UTC and enabled to start emitting at a set time, these transmitters do not loose anytime in placing them back on line, if they go out of service for any reason.

**System Integrity**

This is the ability to provide timely warning to users when the system should not be used. This is achieved by:

1) ***Extensive Signal Monitoring on Site by means of***
   - ***ABS –Automatic Blink System***
   - ***RAIL – Remote Automated Integrated Loran***
2) ***Data Channel***
3) ***Built-in Signal Analyzer***

1. ***ABS***
   USCG has come up with the criteria and specifications for an Automatic Blink System which alerts the users when the transmitter signal is not within the specified limits. By this the integrity of the transmitted signal is constantly monitored. This is an on-site monitor.
   Automatic Blink System (ABS) monitors the transmitted signal for out-of-tolerance conditions through RF feedback and is critical for Loran's performance for integrity protection.
   Automatic Blink is initiated when differences noted in the following major items:
   - Phase of Transmitted Signal vs. Local TOC estimate
   - Phase error in transmitted pulse
   - Lack of RF feedback from transmitter
   - Time step in cesium standard

   ***RAIL***
   Remote Automated Integrated Loran – This enables remote monitoring based on the comprehensive data generated at the site. This provides a vehicle for action to be taken by the remote chain control if and when the system goes into Automatic Blink.

2. ***DATA Channel***
   Eurofix is the method widely accepted and used in Europe and the Middle East. This Eurofix system maintains the integrity of the eLoran System with respect to GPS. This system also propagates UTC information, Unique Station ID, Differential Loran and much other critical and necessary information which strengthens the integrity of the eLoran System.

3. ***Built-in Signal Analyzer***
   The Transmitter Control System (TCS) in the modern Solid State Transmitter comes with a built-in signal analyzer, which

monitors the quality of the transmitted signal. The data can be very helpful in making failure analysis decision so that locally or remotely by the chain control to take appropriate actions for normal operation. This signal analyzer also helps to make critical decisions in switching to redundant units at times of questionable performance.

**Continuity**

This is the capability of the total system to be available for the duration of a phase of operation, presuming that the system was available at the beginning of that phase of operation. This is achieved by:

***1) Switching to TOT Control***
***2) UPS System***
***3) Fast Coupler Switch***

1. ***Switching to TOT Control***
   As mentioned previously, TOT Control helps immensely in terms of minimizing the time to recover an off-air transmitter within the specified time with respect to other stations in the chain.

2. ***UPS System***
   This UPS helps the total availability time of a transmitter as well as lessens to a level almost to zero due to minor prime power disturbances. In most cases, short power outages are transparent to the transmitter that they operate normally without missing a beat.

3. ***Fast Coupler Switch***
   The modern Solid State Transmitters are fitted with RF Switch mechanisms, which will switch from the operating output power unit to the standby unit in less than 3 seconds. This reduces the off-air time or unusable time to almost nil due to a switch over of power units.

**New Receivers to Complement eLoran**

To enhance the performance of the Loran System from transmitting the signal to receiving the signal by the user, modern receivers are also highly improved. Up to now, the legacy receivers were performing to the following criteria and limitations.

- Positioning based on time difference measurements on Loran charts
- System Area Monitors kept Loran accuracy within limits at SAM sites
- TD's may vary at other locations due to different propagation delays and simple timing control.
- Advertised Absolute Accuracy – ¼ nautical mile
- Repeatable accuracy ± 50m.

To complete the enhancement process of the Loran System as a whole, new receivers are being developed with the following key features:

**Key Features of New Receivers**

- Multi chain All-In-View Loran Signal Tracking
- Fast Acquisition (<30 s) & Regular Position Updates
- Interference Mitigation
  - Continuous Wave Interference
  - Cross-Rate Interference
  - Local Interference (Car Engines)
- Groundwave/Skywave Separation
- Reliable Cycle Identification
- ASF and Differential Loran Capabilities
- Integration with GPS
- Data Demodulation and Decoding
- Use of H-Field Antennas to Mitigate P-Static
- Cope with High Receiver Dynamics

Table 4 shows the current status of the Korean chain and therefore briefly outlines some system requirements for the Korea chain to migrate to eLoran.

| DESCRIPTION | STATUS |
|---|---|
| Time of Transmission (TOT Control) | No |
| UPS | Yes |
| Fast Coupler Switch | Yes |
| UTC Sync | No |
| Cesium Steering | No |
| TCS | No |
| ABS | No |
| Data Channel | No |

**Table 4 - System Status of Korea Chain for eLoran**

**5. Conclusions**

This paper has illustrated the latest issues and annual activities for the Loran and Chayka programmes in FERNS. Also presented are some operational and technical matters for the cooperating chains and radio navigation services

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The 16 FERNS stations have been radiating robust Loran-C/Chayka signals for many years. It as an essential source of position and time that can still be relied upon if GNSS failed. However, the users of Loran-C/Chyaka have also migrated to GNSS since the advent of GPS and there are few users left.

Unless the performances of the chains are improved they may not meet the performance requirements to act as backup and complement for GNSS.

The present study was designed to verify how to meet the needs for the improvement of the FERNS chains. This was achieved through the analysis of predicted accuracy performance, with particular emphasis on the Korea chain.

The following conclusions can be drawn from the present study.

- A new station will be needed in the western part of the Korean peninsular to improve the performance of the chain.
- If Ussuriisk stays off-air, a total of at least two new stations are needed to improve the chain and to migrate to eLoran for inland use.
- In order to improve the chain we may need to establish an independent chain or co-operate closely with other chains.
- This research will serve as the basis for future studies that verify and improve the performance of all the all FERNS chains.

Finally, a number of important limitations need to be considered. Firstly, to install new stations, further precise calculations based on measured data collected in FERNS may be needed.

Secondly, there are several practical considerations including economical and political aspects that must be taken into account in improving the chains. In this paper, only technical aspects were taken into account. Finally, the user requirements and system requirements should be reflected upon.

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