# An Assessment Method for eLoran Performance Using the Legacy Loran Signal

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## BIOGRAPHY

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## ABSTRACT

Loran (LOng Range Aids to Navigation) use is in downward tendency, with GPS (Global Positioning System) coming into being the primary replacement. However, some of nations attempt or deliberate to enhance current Loran system, as a backup to satellite navigation system such as GPS being used world-widely. The GNSS (Global Navigation Satellite System) is vulnerable to the disturbance signal, so the radio-based navigation Loran interests in supplemental navigation system by the development and enhancement, which is called enhanced Loran (eLoran), and that consists of advancement of receiver and transmitter and of

differential Loran in order to increase the accuracy of current Loran-C. However, we introduce the assessment method for eLoran performance using the legacy Loran signal by means of ASF (Additional Secondary Factors) measurement technique.

## INTRODUCTION

The current Loran-C system has been developed by DoD (Department of Defense) for the higher performance of position accuracy and coverage area than earlier developed ones: Loran-A and Loran-B [1]. Recently the United States and United Kingdom have investigated constantly for the construction of individual or substitution navigation system in the field of the ocean. The United States almost finished the modernization of Loran system for a supplement and backup to GPS [2], and the United Kingdom expects that related ability and prior occupation about the substitution positioning system through the results of fundamental study managed by GLA (General Lighthouse Authorities) [3]. Increment of the application and use by GPS needs urgently the stable redundancy system and the eLoran is adequate for this purpose because it has different vulnerability to the intended and unintended jamming and the performance is comparable to that of GPS.

In this paper, we present the method of the measurement and assessment of ASF (Additional Secondary Factors) from the traditional Loran-C signal prior to the eLoran scheme. This paper is organized as follows. In Section 1, we briefly describe the key elements of eLoran. The measurement method of ASF using legacy Loran signals is given in Section 2. In Section 3, we present the experiment results of phase lock on and off and head-direction effects on the performance. Finally we conclude this paper with some comments and further researches in Section 4.

## KEY ELEMENTS OF ELORAN

For satisfying HEA (Harbor Entrance and Approach) requirements, it is required to improve the positioning performance when we want to use the legacy Loran system as a backup/substitute system of GPS. Recently, many researchers have been accomplished for improving the performance of the legacy Loran systems and the enhanced system is called as the enhanced Loran (eLoran). In order to satisfy the required performance as a GPS backup system, the three main things are to be established in eLoran systems: upgrading transmitter equipment; synchronizing transmitters to UTC (Coordinated Universal Time) for TOT (Time of Transmission) capability; and broadcasting ASF and UTC information. Especially, it plays an important role in improving the positioning performance to broadcast ASF information by using the LDC (Loran Data Channel).

Legacy Loran system usually shows the positioning accuracy of 400 m ~ 600 m. However, it can satisfy the RNP 0.3 requirements when ASF (spatial term) is corrected by Single ASF value with the accuracy of 30 m ~ 100 m. Moreover, it can even satisfy the HEA requirements when ASF (spatial term and temporal term) is corrected by employing dLoran site within the accuracy of 20 m [4]. As explained above, the correction of ASF has close relationship with the improvement of accuracy. In this paper, we describe a method of evaluating the performance with TOA (Time of Arrival) measurement data of a legacy Loran system when an eLoran system is not yet established.

## MEASUREMENT METHOD OF ASF

The TOA from a legacy Loran transmitter to a receiver can be expressed as:

$$\mathrm{TOA} = \mathrm{RR} + \mathrm{Tx_{delay}} + \mathrm{PD} + \mathrm{Rx_{delay}} + \omega \quad (1)$$

where RR represents real range, $\mathrm{Tx_{delay}}$, PD and $\mathrm{Rx_{delay}}$ are the delay factor of the transmitter system, PD the radio propagation and $\mathrm{Rx_{delay}}$ the receiver system, respectively, and ω is the measurement noise. PD consists of PF (Primary Factor), SF (Secondary Factor) and ASF. For calculating ASF, equation (1) can be rewritten as :

$$\mathrm{ASF} = \mathrm{TOA} - \mathrm{RR} - \mathrm{Tx_{delay}} - \mathrm{PF} - \mathrm{SF} - \mathrm{Rx_{delay}} \quad (2)$$

In Equation (2), RR, $\mathrm{Tx_{delay}}$ is a measurable factor and $\mathrm{Rx_{delay}}$ is considered as an unknown factor. Also, PF and SF can be calculated by modeling [5]. A new TOA measurement method is required because legacy Loran receivers do not directly give the values. In this paper, we used the TOA measurement system as shown in Fig. 1.

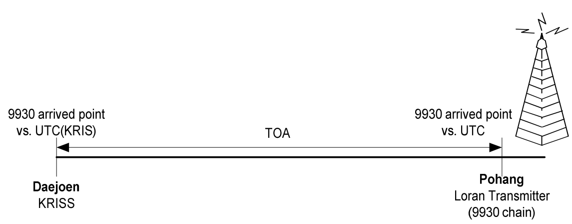


**Fig. 1 Conceptional diagram of the TOA measurement**

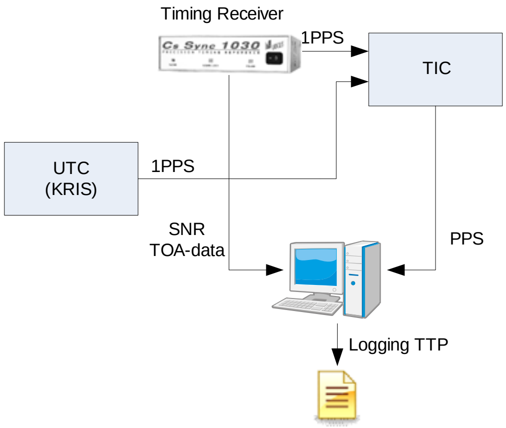


**Fig. 2 Block diagram of the data collection**

The concept of TOA measurement is as follow. We set up legacy Loran receivers in two places (one in each place); KRISS and Pohang Loran transmitter station. Pohang station is the master station of 9930 East Asia chain and designated as 9930M. The ASF of the receiver in Pohang station is conceptually zero and we can calculate the ASF between KRISS and Pohang if we get the TOA differences between them. Fig. 2 shows the block diagram of collecting TOA data. The reference time of the receiver in Pohang is the Loran signal transmitting time of the transmitter and that of the receiver in KRISS is UTC(KRIS). The receiver in KRISS receives the Loran signal transmitted from Pohang station and locks the receiver oscillator to the 6$^{th}$ zero-crossing point of the received signal which has repetition interval of 99.3 ms. The receiver outputs 1 PPS (Pulse Per Second) signal and the additional information such as SNR (Signal to Noise Ratio), ECD (Envelope to Cycle Difference), receiver's TOA data (this is referenced to the receiver's oscillator and we designate it as $TOA_{rx}$) and so on through a serial port. The relationship between TOA and the measured data can be expressed as follow:

$$\begin{aligned} TOA &= T_{UTC} - TOA_{Loran} \\ &= (T_{UTC} - T_{rx}) + (T_{rx} - T_{Loran}) \quad (3) \\ &= TD_{pps} + TOA_{rx} \end{aligned}$$

where $T_{UTC}$ is the UTC(KRIS), $T_{Loran}$ is the time of the 6$^{th}$ zero-crossing point, $T_{rx}$ is the receiver time when it detects the 6$^{th}$ zero-crossing point, $TD_{pps}$ is the time difference between the 1 PPS output of UTC(KRIS) and that of the Loran receiver.

## EXPERIMENT RESULTS

### Phase Lock-on and Lock-off Experiment

In the case of received signals are weak (that is, in low signal strength), this sometimes occurs in a fixed position depending on the weather and environment variation and often for the case of moving inland, the receiver can lose lock to the signals and the measured data is contaminated so can not provide the required performance. Therefore, it is required to find a way which can properly deal with the case. For this purpose, we investigated what happens in the actual state when the receiver loses lock by exacting the experiment of giving 'PLL on (phase lock to the received signals)' and 'PLL off (lose phase lock)' commands to the receiver. Figures 3, 4 and 5 show the measured time difference between the PPS outputs of the UTC(KRIS) and the receiver, the $TOA_{rx}$ output data of the receiver and the values of the time difference plus the $TOA_{rx}$ (from now on, we use the term PPT for this), respectively. The data are obtained through phase lock-on and lock-off experiments in which we alternatively give 'PLL on' and 'PLL off' commands with 3-hour interval. In Figures 3 and 4, it can be seen that the timing jumps occur and their amount are greater than 1 us (about 300 m error in a range estimation) when the receiver loses lock to the received signal. If we use PPT values instead of the time differences, the effect of losing lock can be effectively compensated as we can see in Fig. 5.

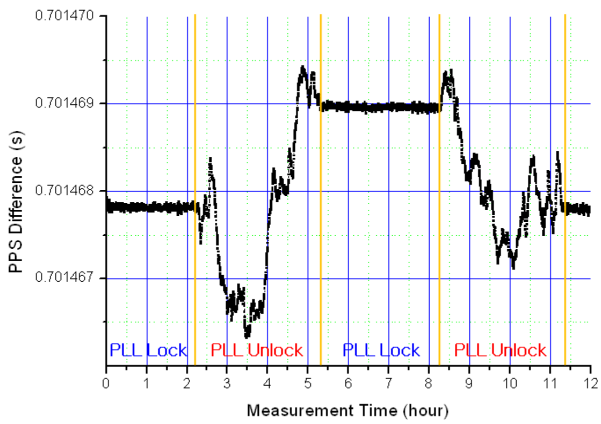


**Fig. 3 PPS values with alternate phase lock-on and lock-off**

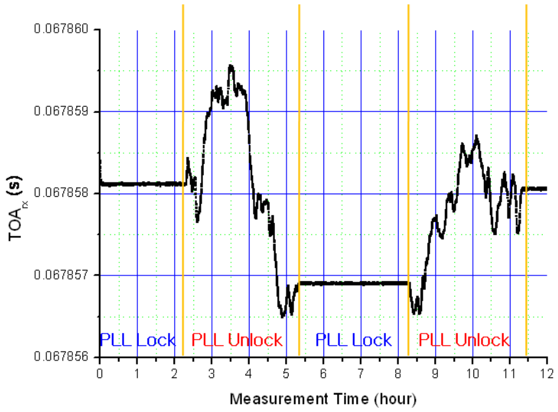


**Fig. 4** $TOA_{rx}$ **values with alternate phase lock-on and lock-off**

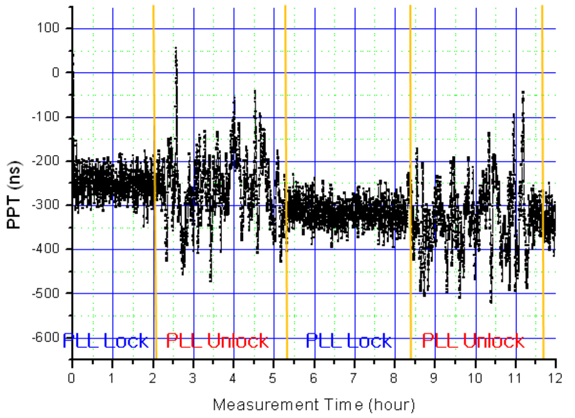


**Fig. 5 PPT values with alternate phase lock-on and lock-off**

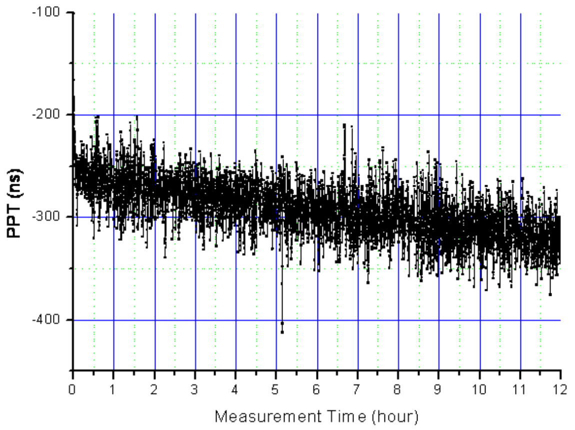


**Fig. 6 PPT values without phase lock-off**

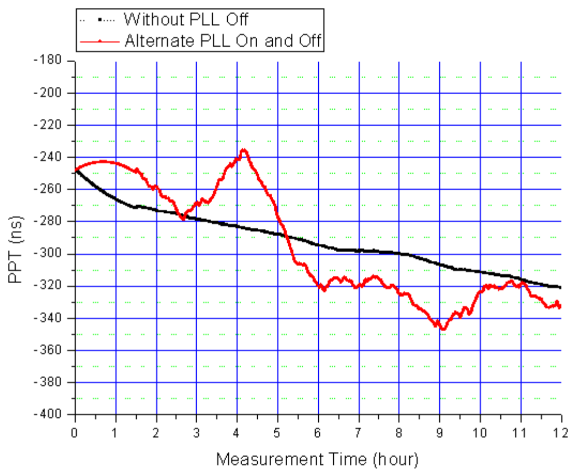


**Fig. 7 Comparison of 3-hour smoothed PPT values between no phase lock-off and alternate phase lock-on and lock-off**

In order to see more closely how much we can compensate the offset caused by phase lock loss, we show the PPT values in Fig. 6 when there is no phase lock-off. As we can see the figure, there is no abrupt phase jump. Fig. 7 shows the comparison results of the smoothed PPT values with 3-hour smoothing interval between the case of keeping phase lock and of alternate phase lock-on and lock-off. The maximum difference between them is about 50 ns and this can cause approximately 15 m range error which would be still large when we should satisfy the HEA requirements. Therefore, more comprehensive method is required to reduce the error through further extensive experiments.

Head Direction Experiment

It is well known that there is head direction effect in a H-field Loran receiver, that is, the TOA value is different when the antenna head direction changes even if in the same position. In order to investigate the effect of antenna head direction on the measured TOA data, we investigated the PPT data with rotating the head direction by 90 degrees in each measurement after aligning the head direction of a receiver antenna to the transmitter. The results are shown in Fig. 8. As we can see in Fig. 8, the variation of PPT value corresponding to 90 degrees change of the direction is about 100 ns. It is very large amount and it maybe one of the critical factor which degrades the positioning performance. Therefore, it is required to align the head direction for acquiring precise TOA measurement data.

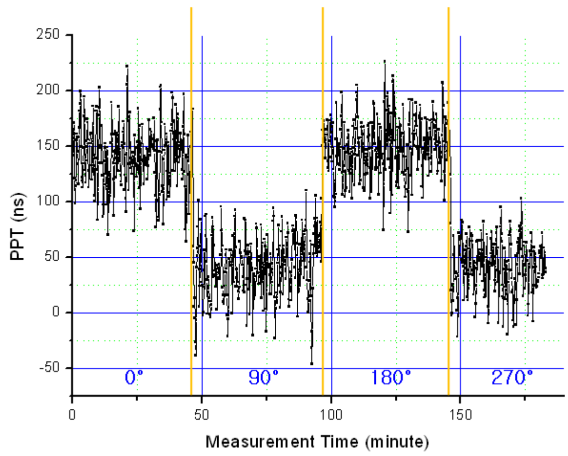


**Fig. 8 PPT values versus antenna head direction**

## CONCLUSIONS

In this paper, we presented a method of measuring TOA data in order to obtain ASF values by using a legacy Loran receiver and investigated the effect of phase lock loss on the measured TOA data through phase lock-on and lock-off experiments. From the experiments, it is observed that the measured PPT (the values of the time difference between UTC(KRIS)'s PPS and Loran receiver's PPS outputs plus the receiver's self TOA output data) data can be effectively used even in the case when the receiver loses phase lock to the received signals. In addition to this, the effect of antenna head direction of a H-field Loran receiver on the measured data was investigated: about 100 ns variation is observed when the antenna head rotates 90 degrees.

In this paper, we presented a method that can be used to obtain TOA measurement values of a receiver at a fixed position. In a further research, we will study on a concrete method of extracting ASF values from measured TOA data between two receivers which are in different places.

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