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# A Study on the ASF Correction Age and Error for Effective eLORAN Data Channel Utilization in Korea

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## ABSTRACT

The vulnerability of GPS to interference signals was reported in the early 2000s, and an eLORAN system has been suggested as a backup navigation system for replacing the existing GPS. Thus, relevant studies have been carried out in the United States, Europe, Korea, etc., and especially, in Korea, the research and development is being conducted for the FOC of the eLORAN system by 2018. The required performance of the eLORAN system is to meet the HEA performance, and to achieve this, it is essential to perform ASF correction based on a dLORAN system. ASF can be divided into temporal ASF, nominal ASF, and spatial ASF. Spatial ASF is the variation due to spatial characteristics, and is stored in an eLORAN receiver in the form of a pre-measured map. Temporal ASF is the variations due to temporal characteristics, and are transmitted from a dLORAN site to a receiver via LDC. Unlike nominal ASF that is obtained by long-term measurement (over 1 year), temporal ASF changes in a short period of time, and ideally, real-time correction needs to be performed. However, it is difficult to perform real-time correction due to the limit of the transmission rate of the LDC for transmitting correction values. In this paper, to determine temporal ASF correction frequency that shows satisfactory performance within the range of the limit of data transmission rates, relative variations of temporal ASF in summer and winter were measured, and the stability of correction values was analyzed using the average of temporal ASF for a certain period.

**Keywords:** eLORAN, dLORAN, temporal ASF

## 1. INTRODUCTION

In 2001, the vulnerability of the global positioning system (GPS) to jamming was raised in the evaluation report of the Volpe National Transportation Systems Center in the United States, and the suitability of the Enhanced LOng RAnge Navigation (eLORAN) for a backup navigation system was evaluated (Volpe Report 2001). Since then, the need for eLORAN has continuously been emphasized as a backup system for the global navigation satellite system (GNSS), and the basic research for the modernization of the LORAN-C system has been carried out in the United States and Europe from 2002 (FAA 2004, U. S. DoD & DoT 2001). Recently, in Korea, the research and development is being conducted for the FOC of the eLORAN system by 2018. LORAN is a ground wave navigation system, which has good stability and repetition accuracy, and robustness against interference. LORAN signals have low-frequency and high-power characteristics, unlike GNSS signals that have high-frequency and low-power characteristics (Wouter 2006).

For the navigation using eLORAN, the required performance is to meet the harbor and entrance approach (HEA) in the coastal area. To achieve the required performance, the correction of an additional secondary factor (ASF), which is the largest error factor for a ground wave navigation system, should be performed. The research on ASF correction has been conducted by the United States Coast Guard (USCG) in the United States and the General Lighthouse Authorities (GLA) in the United Kingdom (Hartnett et al. 2002). Until the early 2000s, the correction methods using a propagation delay model and an ASF prediction model have been studied (Last et al. 2000,

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Shalaev et al. 2006), and since 2004, the correction methods using the actual measurement of ASF have been studied (Kuhn et al. 2006, Johnson et al. 2007). Based on the above studies, in Korea, the ASF correction technique using the prediction model and actual measurement of ASF and the differential LORAN (dLORAN) site utilization plan have been studied since 2009 (Hwang et al. 2009, CNU 2010).

The results of recent studies indicated that for ASF correction, the correction of temporal ASF, nominal ASF, and spatial ASF are required. Ideally, for temporal ASF, real-time correction needs to be performed (CNU 2010). However, in practice, it is difficult to perform real-time correction due to the limit of the data transmission rate of the channel for transmitting correction values. Hence, studies are required to determine temporal ASF correction frequency that shows satisfactory performance improvement within the range of the limit of data transmission rates. Therefore, in this paper, relative variations of temporal ASF in summer and winter were measured, and the stability of correction values was analyzed using the average of temporal ASF for a certain period.

## 2. ASF CORRECTION IN DLORAN

### 2.1 Concept of dLORAN

The dLORAN site is a concept that was introduced by the development of an eLORAN system, and is a system that was added to generate error correction information and to provide the information to users, similar to the DGPS system. The dLORAN site transmits correction information to user receivers by extracting nominal ASF that is a long-term average ASF value of a reference station and temporal ASF that is ASF due to the temporal characteristics of a reference station, from the ASF measured at a fixed position (CNU 2010). To perform these functions, the dLORAN system consists of a monitor site, a monitor server, and a separate data link for transmitting correction data to a transmitting station, as shown in Fig. 1. The monitor site receives LORAN and GPS signals, calculates ASF from the precision position, and then stores them in the monitor server. The monitor server performs the collection and storage of data, converts the received ASF information to LDC format, and then transmits them to the eLORAN transmitting station via TCP/IP at regular intervals (Kuhn et al. 2006, Johnson et al. 2007). Then the eLORAN transmitting station broadcasts the ASF correction to users via LDC. The eLORAN receiver, which received the ASF correction, could remove errors and improve navigation performance using the method proposed by Hwang et al. 2009.

### 2.2 Additional Secondary Factor

ASF can be broadly divided into nominal ASF and spatial ASF that are due to spatial characteristics, and temporal ASF that is due to temporal characteristics (Hwang et al. 2009, CNU 2010). Nominal ASF is generated using the average of actual measurement for the measurement period of at least 1 year, considering the seasonal cycle of the ASF variations in the propagation path of each transmitting station and dLORAN site position. The generated nominal ASF is transmitted to user receivers via LDC. Spatial ASF individually constructs an ASF map for each transmitting station and dLORAN site. Spatial ASF is determined by calculating the relative value for nominal ASF at each grid that was defined for the coverage area of a target dLORAN site. For ASF correction, the storage space of each user receiver should have the ASF map. The best method for obtaining spatial ASF is to use measured ASF that has been repeatedly measured at the corresponding area. ASF due to temporal characteristics is a parameter which is affected by environmental factors such as weather or seasonal change, and it has a large variation rate depending on time. For example, ASF values vary between day and night or between summer and winter. Therefore, the most appropriate method is to transmit error correction information in real time. Unlike ASF due to spatial characteristics, temporal ASF has low sensitivity to the position of receivers, and has a large coverage area of error correction information.

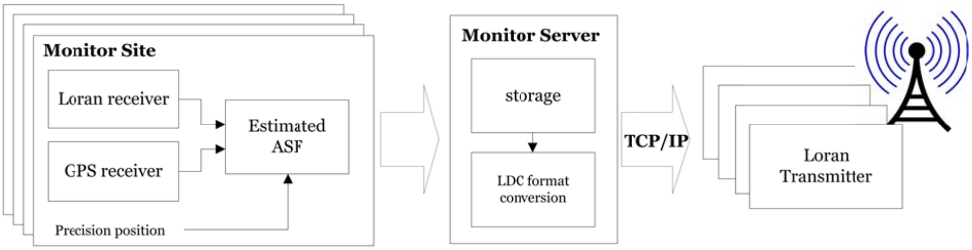

**Fig. 1.** dLORAN system.

**Table 1.** ASF Correction Parameters.

| Parameters | Data acquisition method |
|---|---|
| Nominal ASF | Long-term measurement<br>(over 1 year at dLORAN site) |
| Spatial ASF | Predicted ASF model<br>(e.g. Monteath's model)<br>Measured ASF (repeated<br>Measurement at coverage area) |
| Temporal ASF | Real-time measurement<br>(at dLORAN site) |

Thus, the temporal ASF generated from a dLORAN site is communally utilized by the user receivers within the coverage area. Table 1 summarizes each ASF parameter.

### 2.3 LORAN Data Channel

The modulation techniques, which are the LDC for transmitting data while maintaining compatibility with the existing LORAN-C system, include the modulation technique using 9th pulse (Peterson et al. 2006) and the Eurofix modulation technique (Offermans & Helwig 2003). The method using 9th pulse utilizes the 32-ary pulse position modulation (PPM) method, where modulation is performed using 5 bits as a word unit for each GRI. One message is transmitted every 24 GRI periods. It is a speed that can transmit 45 bits during 24 GRIs, excluding the bits for bit error detection and correction. Therefore, considering the period of GRI, a transmission speed of 18.8 to 47.0 bits/s can be obtained. In a receiver, the 9th pulse for LDC is not included in the tracking process for obtaining measured TOA values, and thus has almost no effect on positioning or time performance. The zero-symbol offset point of the LDC is 1,000 μs after the 8th pulse. Among the 5 bits, the first 2 bits are determined by the coarse delay of the 9th pulse, and the remaining 3 bits are determined by the finer delay. Table 2 summarizes the 5-bit symbols for the coarse delay and the finer delay.

The length of the whole message transmitted via LDC is 120 bits. As shown in Table 3, the detailed configuration consists of the message type (4 bits), the payload (41 bits), and the parity (75 bits) (Peterson et al. 2006)

## 3. AGE OF TEMPORAL ASF CORRECTION

Temporal ASF is the variation factor due to the temporal characteristics of ASF, and ideally, it needs to be measured in real time and be provided to receivers. However, in practice, it is difficult to perform real-time correction due to the limit of the data transmission rate of LDC. Based on the LDC design details to date and the construction status of the LORAN-C Korea Chain, the transmission time of temporal ASF correction can be expressed as Eq. (1).

**Table 2.** 5-bit Symbol Delays (μs).

| *i=[0,7]* | | *i=[8,15]* | | *i=[16,23]* | | *i=[24,31]* | |
|---|---|---|---|---|---|---|---|
| 0 | 0.0 | 8 | 50.6 | 16 | 101.2 | 24 | 151.8 |
| 1 | 1.2 | 9 | 51.8 | 17 | 102.6 | 25 | 153.2 |
| 2 | 2.6 | 10 | 53.2 | 18 | 103.8 | 26 | 154.4 |
| 3 | 3.8 | 11 | 54.4 | 19 | 105.0 | 27 | 155.6 |
| 4 | 5.0 | 12 | 55.6 | 20 | 106.2 | 28 | 156.8 |
| 5 | 6.2 | 13 | 56.8 | 21 | 107.6 | 29 | 158.2 |
| 6 | 7.6 | 14 | 58.2 | 22 | 108.8 | 30 | 159.4 |
| 7 | 8.8 | 15 | 59.4 | 23 | 110.0 | 31 | 160.6 |

**Table 3.** Message type of LDC.

| Number | Type code | Description |
|---|---|---|
| 0 | 0000 | Temporal ASF Correction |
| 1 | 0001 | Nominal ASF Correction<br>Almanac (Reference site positions) |
| 2-14 | 0010 - 1110 | Undefined |
| 15 | 1111 | Reference site timing information |

$$\begin{aligned} T_{Tx,} &= \left(GRI \times 24\right) \times N_{dLor} \\ &= \left(99.3\,ms \times 24\right) \times 43 = 102.5\,s \end{aligned} \tag{1}$$

As shown in Table 3, one message (120 bits) is needed to transmit the temporal ASF correction measured at one dLORAN site, and for the transmission of one message, 24 GRI periods are needed. Thus, considering that the GRI value of the Korean Chain which is currently constructed in Korea is 9930 (99.3 ms) and that the number of dLORAN sites ($N_{dLor}$) to be constructed is 43, it takes about 2.4 seconds. Also, as the number of dLORAN sites selected by the eLORAN system to be constructed in Korea is 43, it takes about 2 minutes to transmit the temporal ASF of the entire dLORAN sites. This transmission time considers only the temporal ASF, but in practice, the transmission of the nominal ASF and timing information of each dLORAN site needs to be taken into account. Thus, considering these, it takes about 4 minutes. Furthermore, if additional important information is put into the undefined message type, the transmission time will become longer. Ultimately, it is expected that a transmission time of more than about 5 minutes is required.

As mentioned above, for the transmission of temporal ASF correction, there exists the limit of the data transmission rate of LDC. Hence, real-time correction is not available and preceding temporal ASF correction data should be used. Therefore, in this section, to determine the correction frequency of temporal ASF, relative variations of temporal ASF were measured, and the correction was performed using the average of these values for a certain period. Then the stability of the measured values was analyzed.

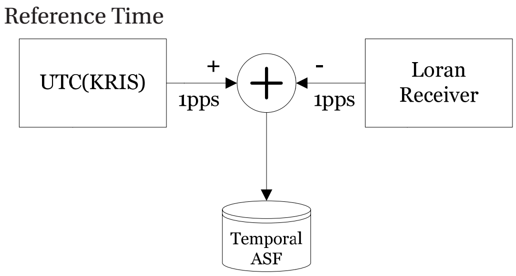

**Fig. 2.** Temporal ASF measurement scheme.

### 3.1 Evaluation environment for the temporal ASF correction age

To measure the relative variations of temporal ASF, the experiment environment was constructed as shown in Fig. 2. For the actual ASF measurement including temporal ASF, the method proposed by Yang et al. (2009) and Choi et al. (2010) can be used. However, in this paper, to analyze the level of performance improvement depending on the correction frequency of temporal ASF, relative temporal ASF was measured, which simplified as the deviation between the 1PPS of the reference signal and the 1PPS signal of the LORAN receiver. In Fig. 2, UTC (KRIS) was used as the reference signal, but in the actual dLORAN site, a clock (e.g., atomic clock and GPS timing receiver) that has stability comparable to UTC (KRIS) will be used.

The relative temporal ASF was measured in Daejeon, Korea for a month in summer (July 2013) and for three months in winter (December 2012 ~ February 2013). The average of the measured temporal ASF for an arbitrary period was obtained and used as the correction value. The correction results were analyzed by varying the time for averaging (2 minutes, 4 minutes, 8 minutes, 30 minutes, 3 hours, 12 hours, and 24 hours).

### 3.2 Evaluation for the age of the temporal ASF

Figs. 3 and 4 show the results in which the averages of the measured ASF for time intervals ranging from several minutes to a day were used as the correction value. They represent the results from the summer data and the winter data, respectively. The correction results using the measured ASF indicated that the stability improved as the interval for obtaining the average becomes shorter. The highest stability was observed when the average of the measured ASF values for a 2-minute interval is obtained and applied to the next 2-minute interval. When the 24-hour average was used as the correction value, the stability improvement was not large. This is because the variation rate or deviation of the measured ASF during 24 hours was high. As the variation accumulated during a day is large, the 24-hour average of the measured ASF is difficult to be regarded as the representative value. Also, the comparison of the stability of the measured ASF in summer and winter at the same time point indicated that the stability was higher in summer than in winter. This is because the temporal ASF variation rate was higher in winter than in summer. In Korea, for summer, the temperature changes within about 15℃ range as the temperature is more than 20℃ above zero even at night; while for winter, the temperature changes within about 25℃ range as the temperature varies from 10℃ below zero to more than 15℃ above zero at noon. It is thought that the above result was obtained because the temporal ASF was significantly affected by the diurnal change characteristics such as temperature. Also, it is expected that if the average for a time interval of more than 24 hours is used as the correction value, there could be sections where the stability becomes rather lower than that of when the ASF correction technique is not applied.

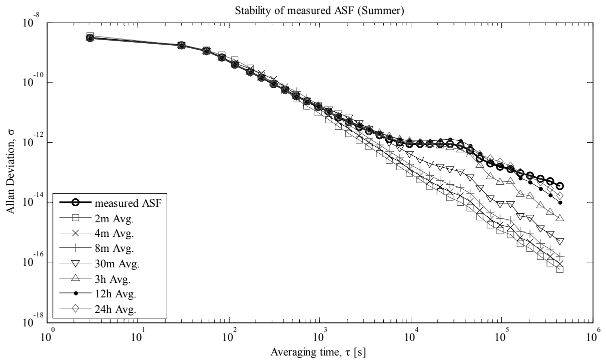

**Fig. 3.** Corrected measurement in summer.

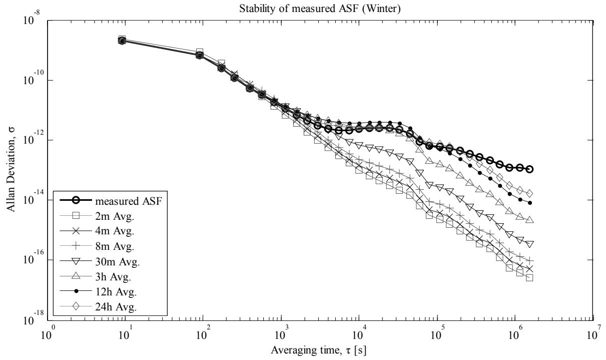

**Fig. 4.** Corrected measurement in winter.

## 4. CONCLUSIONS

In this paper, to determine an appropriate correction period of temporal ASF for the eLORAN system, the

LDC data transmission rate of the eLORAN system was examined, and the performance improvement was analyzed when the averages of the temporal ASF for time intervals ranging from several minutes to 24 hours were used as the correction value. As expected in an ideal dLORAN system, the temporal ASF showed large stability improvement as the correction became more frequent, and the variation of the ASF characteristics depending on seasonal change was also observed. If the temporal ASF of each dLORAN site is transmitted via the LDC using 9th pulse, it is expected that a transmission time of about 5 minutes is required. Therefore, when the eLORAN navigation system is actually operated by installing 43 dLORAN sites in Korea, the stability improvement effect will be similar to the 4-minute average correction results shown in Figs. 3 and 4. If the eLORAN system in Korea uses the Eurofix modulation technique (Offermans & Helwig 2003) as well as the LDC using 9th pulse, the data transmission rate will double, and thus the stability improvement effect could be similar to the 2-minute average correction results. The fact that if the time for averaging is too long, the stability could become rather lower than that of when the correction technique is not applied, indicates that the reference time source to be installed at the dLORAN site needs to be thoroughly examined. If the reference time source installed at the dLORAN site becomes unreliable because of a certain accident, the temporal ASF measurement cannot be performed, and thus the correction value, which is to be provided to LDC, also cannot be renewed. In this case, the eLORAN receiver should use the past data of temporal ASF until the reference time source of the dLORAN site is recovered, and thus performance degradation will occur. Therefore, for the reference time source to be installed at the dLORAN site, the use of reference time source that is vulnerable to interference (e.g., GPS timing receiver) should be avoided, and a precise atomic clock needs to be used. Also, calibration of the reference time source needs to be performed regularly.

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