Transitioning to Time of Transmission Control in the U.S. Loran System

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Abstract

This paper reports on the projected methodologies and potential effects of transitioning the U.S. Loran system to a Time of Transmission (TOT) method of control that is synchronized to Universal Coordinated Time (UTC).

The paper reviews the current method of controlling Loran in the United States using far-field System Area Monitors in a system that is primarily used in the hyperbolic navigation mode.

The paper explores the methods that might be used to transition the U.S. Loran system to Time of Transmission control in an orderly manner, including examining the long-term role of the existing network of far-field Loran monitors. The paper also examines the changes that might be needed to the U.S. Coast Guard SPECIFICATION OF THE TRANSMITTED LORAN-C SIGNAL to accommodate the change in control methodology.

Finally, the anticipated effects of this proposed change in control doctrine on legacy (hyperbolic) Loran receiver performance is examined.

The Long Range Navigation (Loran) system provides a precise, all weather, 24 hour a day radionavigation service. Loran is a low frequency, hyperbolic radionavigation system that operates in the frequency band of 90 to 110 kHz with a carrier frequency of 100 kHz. The Loran User Handbook, COMDTPUB P16562.6, contains basic information concerning the Loran system. The basic element of a Loran system is the chain. A chain consists of a Master transmitting station and at least two Secondary transmitting stations. A Master and a single Secondary transmitting station form a baseline. Each Loran chain provides signals suitable for accurate navigation over a designated advertised user area. Hyperbolic Lines of Position (LOP) are determined by measuring the Time Differences (TD) in reception of signals from the Master and Secondary transmitting stations.

Current Method of Loran System Control: The current method of controlling Loran in the United States is to use far-field System Area Monitors. Loran transmitting stations, currently primarily used in the hyperbolic navigation mode, are constantly monitored to detect signal abnormalities that would render the system unusable for navigation purposes. The control station functions as a real-time monitor of each Loran signal. Monitor receiver sites, located in the user area, are used as the primary source of information regarding system performance. Time Differences (TDs) are controlled to ensure stability of the Lines of Position (LOPs) in the user area. The pulse shape and strength of each signal are monitored to ensure advertised user area coverage is provided. Secondary transmitting stations "blink" to notify users that a baseline is unusable. Chain control parameters are established by U.S. Coast Guard Navigation Center. Control of the Loran system is currently accomplished through three primary elements, control station, transmitting station and system area monitor sites:

1) Control Station: The Loran Consolidated Control System (LCCS), located at the Navigation Center control station receives data from monitor receiver sites and transmitting station equipment. LCCS uses this data to display transmitting station alarms, parameters, and plot data for the control station watchstander. The control station watchstander, using LCCS, can control all the baselines in the chain. The control station's monitoring equipment normally consists of the LCCS, two primary communications links, and backup communications modems. Each control station has a list of LCCS initialization parameters. These parameters change based on operations and seasonal variations.

During normal operations, the control station at Navigation Center has Alpha control of all baselines. The control station monitors the Time Difference (TD) between the Master and Secondary transmitting stations, far field ECD, and signal strength using the monitor receiver sites, Local Station Operating Set (LSOS) and the Automatic Blink System (ABS). In short, the control station functions as a real-time monitor of each transmitting station's data, alarms, and physical condition.

TD is defined as the time interval between receipt of the Master signal and receipt of a Secondary signal as measured by a monitor site receiver. The Standard Sampling Point is the point on the Loran pulse envelope 25 microseconds after the beginning of the pulse in the far-field. For the standard Loran pulse with 0.0 ECD, the amplitude at the standard sampling point is .506 times the peak amplitude. The control station, using information from monitor receiver sites, continuously monitors each baseline TD. By making phase adjustments to the Secondary transmitting station's signal, the TD is maintained near a Controlling Standard Time-Difference (CSTD). The CSTD and tolerances for each baseline are assigned by NAVCEN and are listed in a Chain Operations Order.

The Controlling Standard Time Difference (CSTD) is developed through the following calibration procedure. The Emission Delay (ED) of each station is calculated and set to a value that is published for each station. Calibration of Emission Delay is then accomplished using an equipment suite which directly measures the Time of Transmission (TOT) of each station with respect to UTC. The TOT measurements are made with respect to the Standard Zero Crossing (SZC), 30 microseconds after the beginning of the pulse on the antenna-current waveform at the transmitting site. The TOTs for all sixteen pulses in one Phase Code Interval (PCI) are measured for this calibration. Six TOT readings are recorded for each pulse. Each TOT is the mean value of 100 separate samples of the time difference between the beginning of the reference Group Repetition Interval (GRI) and the SZC of the pulse being measured. When completed, the calibration yields 6 recorded mean TOTs for each pulse in phase group A and phase group B. The Controlling Standard Time Difference (CSTD) offset for the baseline is developed by first calculating the Emission Delay for each secondary by algebraically subtracting the Master TOT from the Secondary TOT. The CSTD correction is then calculated by subtracting the measured Emission delay for the secondary from the published Emission Delay.

The LCCS Time Difference Controller (TDC) keeps the baseline TD from being constantly positive or constantly negative from CSTD, thus keeping the Lines of Position stable in the user area. The TDC calculates and automatically inserts LPAs as required to maintain CSTD. The TDC also generates a plot showing the Time Difference Error (TDE) from CSTD and the Cumulative Time Difference Error (CUM TDE). The CUM TDE is a computation based on the TDE values for the previous 90 minutes. The CUM TDE should sine wave positive and negative across zero.

The TDC is normally operated in the automatic mode for all baselines. In this mode, LPA decisions for a particular baseline made by the TDC are automatically sent to that particular transmitting stations equipment. LPA’s are inserted at Secondary transmitting stations due to normal oscillator drift and short-term changes in the propagation path. LPA’s are not inserted to a Master transmitting station. A single LPA should not exceed 40 nanoseconds in value. The control station watchstander reviews the Bias Plots periodically to ensure LCCS is making the proper LPA corrections to compensate for the present and Cumulative TDE drift. The following guidelines apply:

- If the present and cumulative TDE is positive, LCCS should recommend negative LPAs.
- If the present and cumulative TDE is negative, LCCS should recommend positive LPAs.
- LCCS should not recommend an LPA if the present TDE is positive and the cumulative is negative.
- LCCS should not recommend an LPA if the present TDE is negative and the cumulative is positive.
- LCCS should not insert more than two LPAs in an hour on a baseline.
- The cumulative total for LPAs should not exceed 100 nanoseconds for a baseline during a 24-hour period.

Loran control is always by baseline, not by single transmitting station. There are four modes of baseline control:

Alpha (A) – Baseline controlled using the monitor receiver site.

Bravo (B) – Baseline controlled using Master transmitting station's local receiver locked onto the Secondary transmitting station.

Charlie (C) – Baseline controlled using the Secondary transmitting station's local receiver locked onto another Secondary transmitting station.

Delta (D) – Baseline controlled using the Secondary transmitting station's local receiver locked onto the Master transmitting station.

The table below shows timing **blink** tolerances for specific control modes.

Control Receiver	Parameters	Tolerances
Alpha 1	TD	+/- 100 nanoseconds from CSTD
Alpha 2	TD	+/- 100 nanoseconds from correlated CSTD
Bravo	TINO	+/- 100 nanoseconds from correlated CSTD
Charlie	TINO	+/- 100 nanoseconds from correlated CSTD
Delta	TINO	+/- 100 nanoseconds from correlated CSTD

Envelop to Cycle Difference (ECD) is defined as the time relationship between the phase of the RF Carrier and the time origin of the envelope waveform. In practice, ECD is used to monitor and control the relationship between the shape of the envelope and the Standard Zero Crossing (SZC) of the pulse. ECD is controlled at the transmitting station and monitored by the control station. A Loran receiver typically uses the envelope of the pulse to locate the SZC. The accuracy of the Loran system is dependent upon the ability of a user receiver to properly discriminate the SZC. Therefore, the relationship between envelope shape and the SZC of the pulse must be maintained to ensure user receivers properly acquire the Loran signal.

- Controlling Standard ECD (CSECD) is the assigned far-field ECD that is maintained at the monitor site as determined by chain calibration. The pulse shape is continuously monitored in the user area and compared to the CSECD value. The tolerance for ECD as measured by the monitor receiver is +/-1.5 microseconds from CSECD.
- Far Field ECD (F/F ECD) is the time relationship between the phase of the RF carrier and the time origin of the envelope waveform as measured by the monitor receiver site. F/F ECD is continuously monitored and compared to the Controlling Standard ECD (CSECD). F/F ECD is the value of the transmitting station's ECD as seen in the user area.

The table below shows ECD blink tolerances for specific control modes.

Control Receiver	Parameters	Tolerances
Alpha 1	ECD	+/- 1.5 microseconds from CSECD
Alpha 2	ECD	+/- 1.5 microseconds from CSECD
Bravo	ECD	+/- 0.5 microseconds from EPA Assigned ECD
Charlie	ECD	+/- 0.5 microseconds from EPA Assigned ECD
Delta	ECD	+/- 0.5 microseconds from EPA Assigned ECD

The strength of the radiated signal from a transmitting station has direct impact on the range at which the signal will remain usable. For this reason, the output power level of each station is monitored and controlled to ensure proper system coverage. Monitor receiver site gain is used as an indicator to ensure each transmitting station is broadcasting the signal with enough power to properly cover the advertised user area.

The System Sample (S/S) is a standardized one-hour data collection period that is intended to be representative of typical operations. This is the primary source of data for use in the Loran Operations Information System (LOIS NT). During this one-hour period, data is observed, recorded, and entered in the LOIS NT Daily Detailed Report. The data is collected for each transmitting station in the chain during system sample. Transmitting stations are directed to **not** perform routine equipment switches or maintenance during system sample, and the following circumstances will invalidate System Sample data:

- Equipment switches during System Sample.
- Casualties that affect the On-Air signal or monitor receiver sites.
- Propagation anomalies.
- More than two LPAs on any baseline during System Sample.

2) Transmitting Station: During normal operations, each transmitting station transmits a precisely timed and shaped series of Loran pulses of sufficient power to provide advertised user area coverage. Local signal characteristics are continuously measured at each transmitting station. These measurements can be used by both transmitting and control stations for short-term control or restoration of normal operations following a casualty. A short description of these transmitting station parameters is provided below:

- TINO is the time interval between arrival of the Remote Phase Code Interval (RPCI) signal generated by the receiver and the Local Phase Code Interval (LPCI) signal generated by the Timer. Coarse TINO is continuously monitored at the transmitting station, but is normally used only in the event of a casualty or abnormal condition.

- Peak Volts, as measured by the Electrical Pulse Analyzer (EPA), is derived from the antenna current of the transmitted signal. The current in the ground return path is converted into a corresponding voltage by a current transformer. The voltage generated by the current transformer is measured by the EPA and displayed on the front panel Digital Panel Meter (DPM). The Peak Volts reading is an indication of the output power level of the station.

- Assigned ECD (AECD) is the ECD assignment at a transmitting station which, given existing propagation conditions, results in CSECD being observed at the monitor receiver.

- Nominal ECD (NECD) should be the ECD of the transmitted pulse. Under ideal conditions, when a transmitting station's transmitted ECD is at Nominal ECD, the calculated ECD should be at NECD and the Far Field ECD should be at CSECD. All transmitting stations should maintain their Calculated ECD to within +/-0.5 microseconds of the Nominal value.

3) Primary Chain Monitor Sites (PCMS): Alpha monitor receiver sites are used for long term monitoring and control of transmitting station parameters. They are located in the user area in order to ensure integrity of the Loran system. This type of monitoring is referred to as System Area Monitoring (SAM).

Two Alpha monitor receiver sites are installed in different locations within the user area to monitor each baseline. One receiver is the primary control receiver and is designated as Alpha One (A-1). The other receiver is designated as Alpha Two (A-2). Alarm tolerances for each monitor receiver site are set according to the table below.

Alarm	Alpha-1	Alpha-2
Time Difference Deviation (TDD)	.08	.10
Envelope Deviation (ED)	.10	.15
Gain Deviation (GD)	6	6

Each monitor receiver site has a different set of controlling nominal values based on regional conditions. COCO assigns the nominal values for each monitor receiver site in the chain with the exception of the A-1 CSTD and CSECD and the A-2 CSECD. The monitor receiver site operating values may change based on operations and seasonal variations.

<u>Possible Methodologies to Shift from SAM to TOT Control:</u> The new timing and frequency equipment currently being installed in the U.S. Loran system will allow the option of moving to Time of Transmission (TOT) control and of moving away from the traditional method of system-area monitors (SAM) for control and monitoring of a chain. Adoption of TOT control would maximize the improvement in Loran system performance afforded by the use of "all-in-view" receivers. Such receivers, now becoming available, would no longer be constrained by Loran-chain geometry and would be less susceptible to dilution of precision issues associated with

Horizontal Dilution of Precision (HDOP). In addition, the timing community would receive much tighter control of the Loran signal to Universal Time Coordinated (UTC). Depending on how Loran might be used in the future, the role of SAM sites may even need to be redefined. Briefly, there are three possibilities for transitioning the system to TOT control, station-by-station, chain-by-chain, and whole system. The Coast Guard can be expected to select a control transition approach that offers the minimal adverse impact to the legacy user while giving the maximum benefit to the modern or all-in-view user and the time/frequency users. Before discussing the pros and cons of each transition strategy we need to define what legacy and modern users are in terms of equipment and capabilities.

User equipment capabilities: For the purpose of discussion in this paper, the legacy user has a receiver that is capable of navigation solutions based on time difference (TD) measurements between Master/Secondary station pairs in the currently defined chain configurations. The legacy user's receiver also has the capability to apply Additional Secondary Factors (ASFs) which are TD correctors based on slower signal propagation speed over land than over seawater. Legacy user receivers are using ASFs that are hard coded in their equipment and are based on ASF information provided by the Coast Guard over ten years ago. These Coast Guard provided ASFs are based on a minimal level of field measurements, mainly near the coast because the land-sea interface offers the most dynamic change in signal propagation speeds. In contrast, the modern all-in-view user will have a receiver that is capable of measuring the time of arrival (TOA) for every station that can be received. The receiver will also be able to adjust the measured TOAs for predictable propagation delays via new ASFs. Each ASF corrected TOA measurement gives the receiver a predicted distance from a station or an arc of position. There is considerable effort currently underway to collect LORAN signal data to provide for the generation of new ASFs with an improved resolution over the continental United States. Modern LORAN receivers will be able to take advantage of new ASFs and future ASF updates by storing their ASFs in re-writable memory. The modern receiver will also have a method of resolving its internal clock bias from UTC.

Legacy LORAN user performance factors: The position solution accuracy achievable by the legacy user's receiver is governed primarily by five factors. The first is the geometry offered by the geographical configuration of the station triads in a Loran chain. This geometry results in a set crossing angle of the hyperbolic lines of constant TD between the two Master/Secondary station pairs in the triad. The second is the level of precision of the Coast Guard control of the TD at the monitor (SAM) location. The third factor is the distance between the user and the monitor (SAM) used to measure and make controlling adjustments to the TDs that the user's position solution is based on. The closer the user is to the monitor, the more accurate the user's position solutions will be. The fourth is the accuracy of the original ASFs. These ASFs typically provide the best correction for propagation paths over one land/seawater transition. For a user receiving signals over predomidantly land paths, these ASFs offer significantly less benefit as they are historically based more on predicted or modeled values rather than actual signal measurements. The fifth factor is the accuracy with which the receiver can measure the TD between Master/Secondary station pairs in the chain triad.

Modern LORAN user performance factors: The all-in-view or enhanced user's position solution accuracy is governed primarily by only four factors, vice five as for the legacy user.

The first is again geographical geometry offered by the stations used that will determine the angle at which the calculated distance arcs cross. The advantage for enhanced TOA users is that they will generally always have more stations to use, and therefore better crossing angles of resulting arcs of position. The legacy user is forced to use the geometry offered by a chain's assigned triad Master/Secondary station pairs. The all-in-view receiver can use any station to determine an arc of position and is not constrained to chain triad station geometry. The second accuracy factor for the all-in-view user is the precision with which the Coast Guard maintains each station's broadcast to synchronization with UTC. The third factor for a modern user is the precision of the ASFs used to correct the TOA measurements for geographic propagation delays. The fourth factor is the accuracy to which the receiver can measure the TOA of each received signal.

Impact of TOT control on legacy user: It is difficult for the Coast Guard to accurately determine the size of the current legacy user base in North America and therefore the level of concern that should be given to minimizing the legacy user impact during a system control transition. Historically the Coast Guard has provided users public notification of any changes to the operations of a radionavigation system. In the strictest technical sense, a change to TOT control would still allow the system to meet all performance requirements currently given in the Coast Guard published LORAN signal specification. However, legacy users have come to expect repeatable accuracy of LORAN that is much better than the quarter mile absolute accuracy performance published. Legacy users know that they can achieve between 17 to 90 meters in repeatable accuracy, depending on triad station geometry and distance from the TD controlling monitor (SAM). Within roughly 100 nautical miles of SAM the legacy user can expect to return to a LORAN waypoint with an accuracy of around 50 meters if the LORAN waypoint was generated within a week or so. It is believed that a change to TOT control will offer improved accuracy performance over increased coverage areas for the all-in-view multi-modal user. TOT control can however be expected to change the historical repeatable accuracy for the legacy user in many locations of the current chain coverage. Because of the expected change of historical repeatable accuracy performance, the Coast Guard should publish a Federal Register notice announcing an intention to change from SAM to TOT control. The same public notice could solicit user comments. The response to this Federal Register notification will probably be the only mechanism for the Coast Guard to accurately gauge the number of legacy users and their level of concern over degraded repeatable accuracy performance with a switch to TOT control. The predicted level that repeatable accuracy will change overall is discussed in the last section of this paper. This paper does not have the benefit of knowing what legacy user response will be to a Coast Guard notice of intent to shift to TOT control. Therefore it will be assumed that a sufficient response will be received to cause the Coast Guard to select a method of transition that will offer reduced negative impact to repeatable accuracy over a sufficient time for legacy users to transition their equipment to a modern all-in-view receiver.

LORAN Master Stations are already in TOT Control: Before addressing each of the SAM to TOT control transition options there are two other historical factors that should be briefly covered to complete the foundation for the control change discussion. First, it must be noted that the Coast Guard has been using TOT control for all Master LORAN stations for some time. That is, all Master rate broadcast timing is steered by the Coast Guard to maintain a level of synchronization to UTC. Prior to Public Law 100-223, the Airport and Airway Safety and

Capacity Act of 1987, Coast Guard policy was to maintain each Master rate UTC synchronization to within 2.5 microseconds. To comply with Public Law 100-223 the Coast Guard now works to synchronize each Master rate to within 100 nanoseconds, or 0.1 microsecond of UTC. To maintain UTC synchronization the Coast Guard has relied on USNO to provided daily predictions of each Master rate's offset from UTC. USNO has done this by monitoring LORAN signals over unmodeled propagation paths. However, the USNO observations are highly filtered to minimize the daily propagation variations and as a result the Coast Guard is often not responsive enough with Master rate time steering to truly maintain 100 nanosecond synchronization. Consequently, the Coast Guard has over the last decade worked with USNO to develop a more direct measurement of each LORAN Master rate's offset from UTC.

New LORAN Station timing equipment vastly improves synchronization capability: When the FAA began funding a major recapitalization of LORAN infrastructure, it provided the opportunity for designing a new LORAN station timing and control suite (TFE). The TFE equipment design and development has been completed and is now being installed at LORAN Station George. The new TFE has been designed to steer the Master rate to UTC to within 10 nanoseconds. This ten-fold improvement over the Public Law requirement is due to direct time transfer with USNO via GPS and the creation of a local clock ensemble at each LORAN station with the three Cesium oscillators available. The new TFE also was designed to improve the LORAN signal utility to time and frequency users. The old LORAN station timing equipment was only capable of a minimum adjustment in 20 nanosecond phase steps. While this was small enough to not bother many frequency users, most time users found it problematic particularly if the Coast Guard made phase steps to the an entire chain (including the Master). The new TFE is capable of making broadcast signal phase adjustments by steps or by steering the phase over a short period on the order of a minute. It will be possible to implement steered phase adjustments to provide a signal that will benefit all users: navigation, time and frequency. It is important to note that TOT control is not realistic unless two pieces of new equipment have been installed under the FAA recapitalization project. The LORAN station must have the new TFE installed to allow TOT control for any rate broadcast from the station. Further, the LORAN Control Station equipment must be upgraded to provide for a TOT control interface to stations with the new TFE. The LORAN recapitalization project schedule has the upgraded LORAN Control Station being installed at the two LORAN Control Stations before the end of 2003. The TFE installations are expected to be completed at all stations by the end of 2005. Now we will consider the three options for shifting from SAM to TOT control.

Station-by-Station Option: First, we will give consideration to changing control on a station-by-station basis. This would offer the most gradual and longest transition period for the legacy user, but also provide the all-in-view user with small incremental improvements over the entire period of the FAA's recapitalization project. This method would meld nicely with the FAA project because, as new station equipment installations are completed, each station could be moved to TOT control. The new equipment is also fully capable of SAM control as well and, in fact, can support TOT control on one Loran rate and SAM control on the other at dual rated stations. The method of TOT control implementation would also allow for a validation period of the expected improvements before a large portion of the LORAN network has actually been shifted to TOT control. A drawback is that this option for transition would increase the level of complexity for the LORAN Control Station watchstander, especially during the recovery of a dual-rated station from an equipment casualty. The watchstander would need to remember which stations and rates are under TOT control and which are under SAM control. This means that the Coast Guard would need to at least double the training and exercise required for each control watchstander to maintain signal reliability. Therefore, the station-by-station option benefits the legacy user and provides for a performance validation period, but at the expense of complicated control and slower implementation of modern navigation, time and frequency user benefits.

Chain-by-Chain Option: The second option is the transition to TOT on a chain-by-chain basis. This option would speed up the implementation of benefits for the modern navigation, time and frequency users and still offer a phase-out period for the legacy user. This option also would provide for a performance validation period within the coverage area of the first chain transitioned to TOT before transitioning additional chains. Another benefit would be to industry since there would be a region of TOT control in which modern user equipment could be tested, refined and demonstrated. This option still has the drawback of more complicated LORAN Control Station operations during the transition period. While it may not be as complex for the control watchstander as the station-by-station approach, there would still be stations with one rate in TOT control and one in SAM control. Each watchstander oversees two chains, so the period of possible confusion could be minimized by scheduling the transition of the second chain in sequence after the watchstander's first TOT chain. This option offers increased benefit for modern users and for new user equipment development along with more manageable control operations. It however, would change the legacy user's repeatable accuracy performance an entire chain at a time. This could be less confusing for the legacy user than a station-by-station transition as the legacy user uses LORAN stations in a chain configuration and not as individual broadcasts.

System Option: The final option is to transition the entire LORAN network, or all chains, at a single coordinated time and date. This would offer the legacy user the longest period of unchanged repeatable accuracy performance. However there would be no phase-in period of the change in legacy service as it would happen at the instant of transition to TOT control. The modern user would also have to wait the longest period of time before realizing any benefit in LORAN service from the new recapitalized equipment. This option may offer the least complexity and risk to the continuity of LORAN control operations, but there would be no opportunity to cross-train control watchstanders during a period when both TOT and SAM controlled stations would be present on a control console. Certainly, this option would provide the best situation for the programmers developing the new LORAN Control Station software. They would not have to field a software version capable of operating with a mix of TOT and SAM controlled rates. The down side is that there would also be no field operational experience with the TOT control software or operations before the day it was scheduled to go into service. Industry and manufacturers would also not have an early region of coverage for user equipment testing and demonstrations. A LORAN signal simulator may have to be utilized for those that want to develop new products to take full advantage of the improvements offered by tightly UTC and GPS synchronized TOT controlled LORAN. In summary, the transition as an entire system offers the longest period of status quote for the legacy user and the least complication for control operations, however, it provides no early benefits for modern users, service validation period, or industry development.

Best Control Transition method is Chain-by-Chain: Upon consideration of the options, the authors conclude that transitioning chain-by-chain is the best alternative. It offers the best compromise between the individual concerns:

- Provides the legacy user a phase-out and the modern user a phase-in period during 2004 and 2005.
- Reduces confusion for both users and control watchstanders as to what coverage is under what control method.
- Provides one chain of modern LORAN coverage under TOT by mid-2004 for performance validation and user equipment tests.

What happens to SAM monitors with change to TOT control: Once the LORAN system transitions to TOT control, there is a question as to what will happen to the SAM monitor sites. These site were recapitalized just two years ago with each site receiving a modern monitor receiver, antenna, new software, and data communications circuit. These sites should not be disestablished. They will still be required to monitor and control signal parameters. The sites should continue to monitor Envelope-to-Cycle Difference (ECD) and Signal Strength (SS). The Control Stations would depend on these sites to detect ECD and SS out-of-tolerance conditions in the user coverage area. The monitor sites should also continue to collect SNR data. However, they would no long collect TD data. They should be switched over to their capability to monitor and collect TOA data. This data could be used during the first several years in TOT control to verify and validate system performance in the user coverage area. These monitor sites could also be used to provide data for and monitor the proposed LORAN data channel.

Anticipated Changes to the U.S. Coast Guard Loran-C Signal Specification: There are several initiatives associated with the development of a modernized Loran that may result in changes in the broadcast signal, methods of control, and methods of communications with the users in real time. While many of these changes are still under development, several directions have begun to take shape. The modernized Loran of the future seems likely to exist in the United States as a Time of Transmission controlled system intended primarily for use by all-in-view receivers. It would incorporate an additional data channel intended for the purpose of providing near-real time temporal Loran correctors to high accuracy users of the modernized Loran system. As currently envisioned, the system would likely remain backwards compatible with legacy hyperbolic Loran-C receivers. It would further be compatible with the method of tri-state pulse position modulation which has been adopted by several countries as a method of disseminating GNSS augmentation signals.

Any changes ultimately adopted for incorporation into the U.S. Loran system would need to be documented in the "Specification of the Loran-C Signal" published by the U.S. Coast Guard. The Signal Specification is intended as a reference document consisting of definitions, specifications, and explanations for general distribution to designers, manufacturers, and users.

Since the publication of the current Signal Specification in 1994, the Loran-C system has undergone significant recapitalization and modernization. Several new sub-systems have been implemented or are in the process of being implemented by the U.S. Coast Guard.

- new solid-state transmitter (nSSX), manufactured by Megapulse, Inc., in Massachusetts to replace the AN/FPN-44A/45 tube-type transmitters,

- new Timing and Frequency Equipment (TFE), manufactured by Timing Solutions, Inc., in Colorado to replace the AN/FPN-54A/65 Timing and Control Equipment, and

- new control and monitoring equipment developed at LSU in New Jersey and at Locus, Inc., in Wisconsin, made up of the Remote Automated Integrated Loran (RAIL), the Locus Receiver Timing Monitor Status System for local monitoring and control, the new Loran Consolidated Control System (nLCCS), and the Primary Chain Monitoring Set (PCMS) for remote monitoring and control. All of these new software-intensive sub-systems, produced by different entities in different locations, have been integrated with each other and with existing sub-systems to work together as an overall system. On October 23, 2003, the Loran station at George, WA, began operational broadcasts from its newly installed nSSX, TFE, and new operations suite of equipment.

<u>Blink</u>. There is an elevated concern over the integrity of the Loran-C system. Methods are being considered to both detect and communicate to the when hazardously misleading information is being broadcast. The traditional methods of monitoring the signal are being reevaluated (e.g., the use of system-area monitor (SAM) sites). The traditional methods of blinking the signal (i.e., turning off the master signal or repetitively turning off and on a secondary signal) to alert users may be redesigned.

<u>Loran Data Channel</u>. Methods of using the Loran-C signal to broadcast temporal correction, timing, and integrity information are being considered. One proposed method is to add an additional pulse to all stations. The additional pulse would be inserted between the eighth pulse and the master 9th pulse at master stations. The additional pulse would be added following the eighth pulse at secondary stations. In both cases, this pulse would be modulated to carry information. If adopted, this would require several changes to the Signal Specification:

- Pulse-to-pulse timing descriptions would have to be redefined.

- The continued need for or the role of Master 9th pulse blink as a communications method would have to be determined.

- The continued need for or the role of Two-Pulse Comms would have to be determined.

<u>Differential Loran</u>. The concept of Differential Loran is being developed to improve Loran system accuracy for both navigation and timing users. Currently, the U.S. Coast Guard and the

U.S. Army Corps of Engineers (USACE) have partnered in a localized test of this concept. If ultimately implemented, this technique would have to be adequately described to the user segment. In addition, the methods used to gather spatial and temporal corrections would have to be adequately described.

Early Skywave. The effects of early skywave on the integrity of Loran-C in the continental United States are being studied. There are different options being considered to mitigate this concern. One proposal is to quicken the rise time of the pulse and/or make other signal-structure changes. If adopted, these would require changes to Signal Specifications affecting spectrum characteristics and the pulse leading edge would have to be redefined. Depending upon the new signal structure, the definition of ECD and its control might have to be redefined.

Anticipated Effect on Legacy Receivers: Public Law 100-233 required a study of the impact on legacy users if the secondary LORAN station transmission were also synchronized to plus or minus 100 nanoseconds of UTC. The study was completed and a report was prepared. The study used the Double Range Difference (DRD) model to analyze the impact on the repeatable accuracy of the five LORAN chains covering the continental United States. The DRD model was modified to predict LORAN repeatable accuracy performance if both Master and Secondary station transmissions were synchronized to UTC by TOT control. The model produced a series of contour charts predicting the repeatable accuracy for each LORAN chain. One chart shows the prediction for SAM control and two charts show predictions for TOT control; one with stations synchronized to within 30 nanoseconds (1 sigma) of UTC, and a second with stations synchronized to within 100 nanoseconds (1 sigma) of UTC. The study concludes that there are predicted to be small inland regions where repeatable accuracy improves with a shift to TOT control and synchronization of all stations to within 30 nanoseconds of UTC. There are significant areas in the coastal regions where the repeatable accuracy is predicted to degrade. The overall prediction is for a net loss of repeatable accuracy. The results vary significantly from chain to chain. For instance, the predictions show the same repeatable accuracy for the Canadian West Coast (5990) Chain for SAM control as for TOT Control with 30 nanosecond synchronization. On the other end of the results spectrum are predictions for the North East US (9960) Chain, which shows 50 meter repeatable accuracy degrading to 100 meters from the Virginia coast to the offshore areas of New England, but with a corresponding increase in the 50 meter contour area in parts of Pennsylvania, Ohio, and West Virginia. In short, the study raises concerns for loss of repeatable accuracy if synchronization to only 30 nanoseconds is achievable. It is omportant to remember that the study was completed nearly ten years ago and the improved capabilities in time and frequency control afforded by the new TFE was not considered. Indeed, the study noted that even achieving UTC synchronization within 30 nanoseconds would be difficult to do. However, the new TFE just installed at LORAN Station George, Washington can maintain station time synchronization to within 10 nanoseconds of UTC, and possibly even to within 5 nanoseconds. Measurements should be made at George to determine how tightly the new TFE can maintain synchronization. Then the Coast Guard should consider revalidating the Public Law 100-233 study's modeling effort using bounds on the error budget that would be achievable today. With synchronization to within 10 nanoseconds of UTC a shift to TOT control could well bring far less change in the repeatable accuracy performance than anticipated.

The Coast Guard should also examine other methods to minimize any change in the repeatable accuracy performance. One method would be to look at reassigning Emission Delays for each secondary station to put them in the middle of historical propagation variations. The application of a historically based offset to the Emission Delays may result in least amount of delta in repeatable accuracy for legacy users.

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