# VALIDATION OF A TIME OF TRANSMISSION MONITOR SUITE FOR MEASUREMENT OF THE OFFSET BETWEEN LORAN-C TRANSMISSIONS AND UTC

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Abstract

***The U.S. Loran-C system is an integral part of the national infrastructure for the dessimination of precise time and ime interval. In 1997 the U.S. Coast Guard Loran Support Unit located in Wildwood, New Jersey, developed a Time of Transmission Monitor (TOTM) suite. The TOTM suite will be used to measure the average daily offset between UTC and the time of transmission of a Loran-C station. Direct measurement of the time of transmission of the Loran-C signal with respect to UTC will allow the Coast Guard to more tightly couple the Loran-C system to UTC. This paper will discuss the effort, jointly undertaken by the U.S. Coast Guard and the U.S.Naval Observatory, to implement and validate the TOTM equipment suite.***

## INTRODUCTION

Loran-C is a long-range radionavigation system, which is operated in the United States by the U.S. Coast Guard. The U.S. Loran-C system is operated in concert with Loran-C stations in Canada and with a Russian CHAYKA station to provide radionavigation coverage for the entire continental United States and most of the sub-arctic areas of Alaska and Canada.

The primary requirement for operation of the Loran-C system is to provide the maritime and general aviation community with a long-range radionavigation service. However, the Loran-C system is also recognized as a component of the national Precise Time and Time Interval (PTTI) infrastructure. Synchronization of Loran-C transmissions with Coordinated Universal Time (UTC) allows the Loran-C system to be used for the dissemination of UTC. Cesium-based oscillators provide each Loran-C station with a highly stable source for derivation of the 100 kHz carrier frequency. This allows the Loran-C system to be used as a precise time interval source.

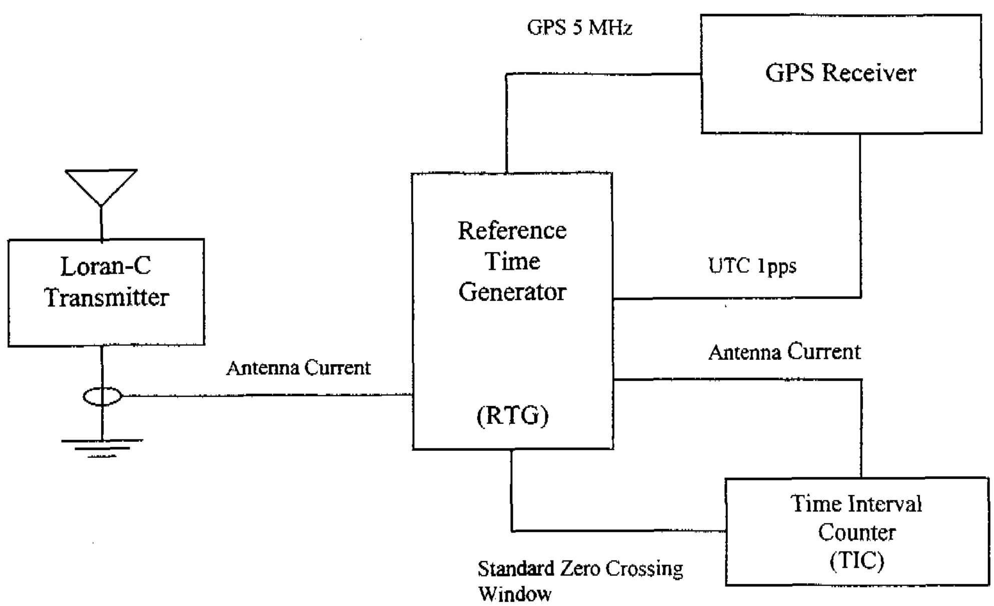
Public Law 100-223, enacted by Congress in 1987, requires timing of Loran-C master transmissions to be held to within 100 nanoseconds of UTC. Control of the offset between Loran-C master transmissions and UTC has traditionally been accomplished using far-field Time Of Arrival (TOA) information measured by the U.S. Naval Observatory (USNO) using Loran-C timing receivers at various locations throughout the country. The TOA of the Loran-C master signals observed by the receiver at a given location is compared to the UTC standard maintained by USNO at that location. The offsets for each Loran-C master transmission are analyzed over a period of time to determine the relationship between the Time Of Emission (TOE) of the master signal and UTC. Once sufficient analysis has been accomplished to establish the Loran-C TOE/UTC relationship, adjustments can be made in the form of either master oscillator frequency changes or TOE changes.

Holding the offset between UTC and each Loran-C master TOT to within 100 nanoseconds has been a difficult task. Data gathered using far-field receivers are prone to systematic noise resulting primarily from changes in the propagation path delay. Short-term as well as long-term changes in the propagation path affect the time required for the Loran-C signal to travel from the transmitting site to the far-field receiver. Short-term effects, noticeable over several days, are predominately the result of weather fronts moving through the propagation path. Long-term effects are seasonal in nature and are noticeable over several months. Diurnal changes can also be recognized, however, averaging a set of samples taken over a twenty-four hour period can mitigate these.

As a means of improving the quality of the data available for control of the offset between UTC and the Loran-C master TOE, the U.S. Coast Guard Loran Support Unit located in Wildwood, New Jersey, has developed a Time Of Transmission Monitor (TOTM) suite. Two prototype installations of the TOTM equipment have been under evaluation over the past year at Loran Station Williams Lake, Canada, and at Loran Station Seneca, New York.

## TIME OF TRANSMISSION MONITOR

The prototype TOTM suite consists of a GPS timing receiver, a time interval counter, a reference time generator (RTG), and a clamp-on current transformer. With the exception of the RTG, the components are all commercially available. The U.S. Coast Guard Loran Support Unit developed the RTG.



### GPS Timing Receiver

The GPS timing receiver provides 1PPS and 5 MHz waveforms that are stabilized to UTC (GPS) with an accuracy of 40 nanoseconds RMS.

### Time-Interval Counter

The time-interval counter has time base stability on the order of 2.5 x $10^{-9}$ and measurement resolution of 750 picoseconds. It can also perform limited statistical computations on up to 1 million measurement samples.

### Reference Time Generator

The RTG provides a means of generating a Standard Zero Crossing (SZC) window at the Loran-C rate being measured. The SZC window is calibrated to a UTC reference provided by a 1PPS reference.

### Clamp-on Current Transformer

The clamp-on current transformer provides a means of obtaining a sample from the transmitting antenna current. The antenna current sample is provided to the TIC for use in the offset measurement.

### TOTM Functional Description

The Time Of Transmission Monitor suite is designed to measure the offset between UTC and the start of the first of sixteen pulses in a Loran-C Group Repetition Interval (GRI). To accomplish this, the 5 MHz output of the GPS timing receiver is used by the Reference Time Generator to develop a Standard Zero Crossing (SZC) window that is calibrated to UTC and which occurs at the same rate as the Loran-C transmission that is being measured. The SZC window can be used for direct measurement of the Standard Zero Crossing of the transmitted Loran-C pulse. The SZC window is provided to the start input of the Time Interval Counter (TIC), while the Antenna Current waveform from the clamp-on current transformer is provided to the stop input.

The TIC samples a time difference between the SZC window and the Standard Zero Crossing of the antenna current waveform once every GRI. For the Loran-C rate 59900 microseconds, this results in approximately 721,000 measurement samples in a twenty-four hour period. The TIC uses simple statistically analysis to determine the mean and standard deviation of the each twenty-four hour sample set.

## TOTM VALIDATION

Loran Support Unit completed installation of two prototype TOTM suites at Loran Stations Williams Lake, British Columbia, and Seneca, New York, in the fall of 1997. The installation at Loran Station Williams Lake was accomplished to fill a need for UTC offset data for that station that was not otherwise available. The prototype installation at Loran Station Seneca was accomplished to provide us with the ability to compare the data set gathered from the TOTM suite against the data set obtained from the tradition far-field measurement method. Evaluation of the data obtained from these two installations began shortly thereafter.

Early comparison of the data sets gathered from the two sites led to the following observation: the data set from the Williams Lake installation had much less noise than did the data set from Seneca. We hypothesized that the increase in noise in the Seneca data was the result of a more aggressive oscillator management protocol being used for that station. Early in 1998 we set out to prove this. For a period of two months we discontinued adjustments to the 9960-Master oscillator. We found that the apparent noise in the measurement diminished significantly, confirming our hypothesis. This information was used to modify our control protocol for the 9960-Master oscillator. Data obtained for the period following these changes show a reduction in noise in both the USNO data set and the TOTM data set.

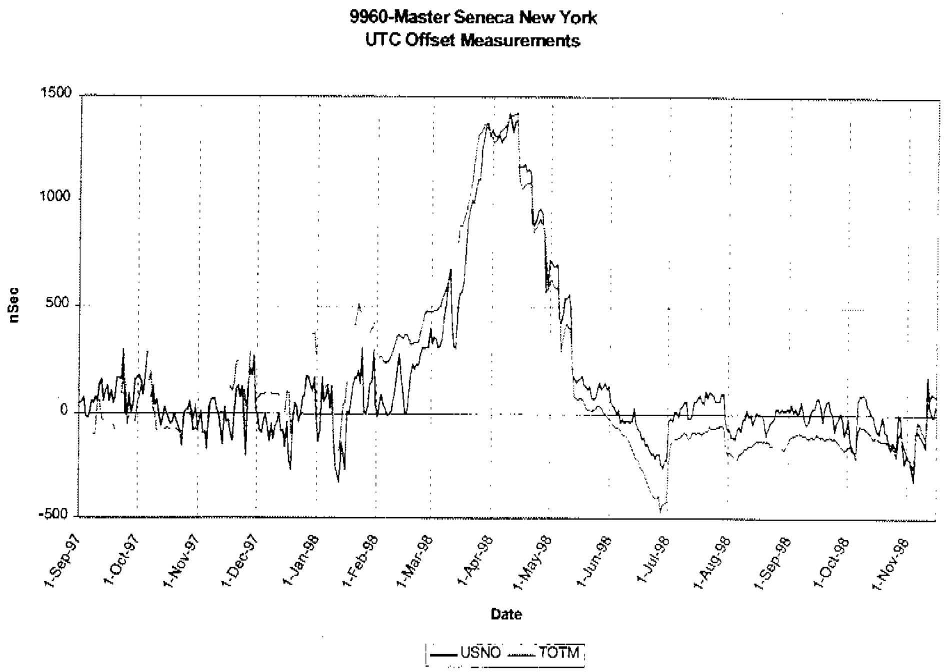
## Comparison of the Seneca TOTM and USNO Data Sets

Acceptance of the TOTM measurement method required validation ot the method beyond a theoretical analysis. Historically, the U.S. Naval Observatory has provided the Coast Guard with daily measurement of the offsets between UTC and the Loran-C master station transmissions. In February of 1998, the Coast Guard and USNO agreed to conduct a joint validation of the TOTM measurement method.

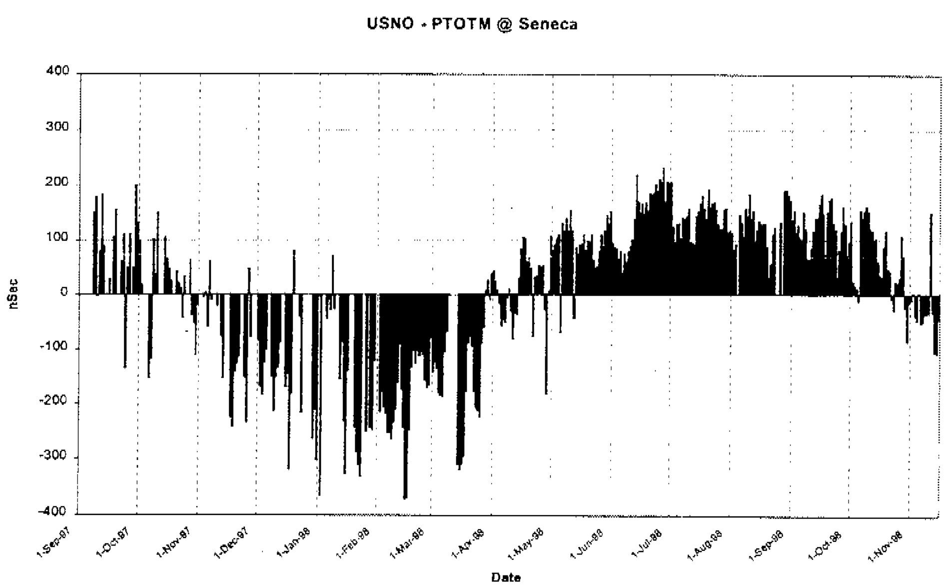
Early comparison of the TOTM and USNO far-field data revealed a difference in the offsets being reported by the two measurement systems. There was also a significant difference in the degree of noise seen in the two measurement sets, the USNO far-field data showed a much higher degree of noise. This led us to believe that the most likely source of error in the two measurement systems was the propagation model being used in the far-field measurement method.

In an attempt to eliminate or significantly reduce this potential source of error, a joint USNO and Coast Guard experiment was conducted during March 1998. Three sets of near far-field measurements were taken within a 17-mile radius of Seneca, New York. The measurements compared the Time Of Arrival (TOA) of the Loran-C transmission from Seneca against a Hewlett Packard 5071 Cesium Frequency Standard that had been calibrated to UTC at USNO. An Austron 2100 Loran-C receiver was used to receive the Seneca transmission. This experiment proved to be inconclusive. The inherent cumulative errors of the suite used for the near far-field measurement proved to be greater than the precision needed to validate the TOTM suite.

To resolve the differences seen in the data from the TOTM and USNO measurements, we returned to analysis of the data itself. For a period of time from June through September 1998 it appeared as if there was a fairly constant offset between the two measurement sets. This led us to speculate on the presence of a systematic error that had not yet been accounted for. As time passed, it became apparent that the differences that we were seeing were not constant. In October of 1998, the data began to converge.




A long-term analysis of the two data sets over the entire fourteen-month sample period reveals a clear trend. The two data sets converge and diverge over the course of the year and cross twice a year.




A plot of the daily differences between the two data sets over the fourteen-month period makes the annual trend very apparent.

Once the annual trend in the daily differences between the two measurement systems was identified, analysis of the overall effect of the phenomenon was conducted. We found that the mean of the daily differences taken over a twelve-month period (approximately one cycle) is on the order of 12 –15 nanoseconds. However, the standard deviation of the mean is rather high at 140 nanoseconds. Upon further analysis of the data, we noticed that the two measurement systems react differently to a time step. When a two-day period following each Loran-C time step is removed from the data sets, the mean remained nearly the same, while the standard deviation improved significantly. This indicated that there is good long-term correlation between the two measurement systems.

The next step was to identify the source of the annual trend. Our initial hypothesis was that, because of the seasonal nature of the trend, it must be related to changes in the propagation path delay. This led us to analyze the method used to resolve the far-field Time Of Arrival (TOA) measurements into Time Of Emission (TOE) UTC offsets. We found that the TOA offset data are converted to TOE offset data by applying a constant value, which represents the predicted propagation path delay and the near-far field transition. Application of a constant does not permit the propagation path model to adapt to seasonal changes in the propagation path delay. This was clearly a source of significant error in the far-field measurement method that would not be present in the time of transmission measurement method.

## CONCLUSIONS

From analysis of the data obtained over the past fourteen months from the two measurement systems, the following conclusions can be made:

(1) there is a difference in the measurement system that is cyclical in nature with a period of approximately one year,

(2) the most probable source of the difference seen in the two measurement systems is the lack of compensation for seasonal changes in the propagation model applied to the far-field measurements,

(3) the mean of the daily differences seen in the two measurement systems is small, indicating that there is good long-term correlation between the two systems,

(4) the TOTM measurement system provides data that contain far less noise than the data obtained from far-field measurements,

(5) implementation of the TOTM measurement data as the primary means of control for Loran-C Master station timing would be advantageous in terms of our ability to improve the synchronization of the Loran-C system with UTC

(6) continuation of far-field measurement capability is desirable to ensure long-term stability of the system and to provide data for long-term analysis of the effect of changes in the propagation path.

## ACKNOWLEDGMENTS

The assistance provided to the Navigation Center by U.S. Naval Observatory and Loran Support Unit during the prototype assessment has been invaluable in helping us to understand the measurement processes used by both the traditional far-field system and by the TOTM system.

I would like to recognize the contributions of Dr. Dennis McCarthy and Mr. Harold Chadsey of the U.S. Naval Observatory, Time Services Division, in helping us to identify and understand the difference seen in the two measurement systems.

Particular thanks are extended to Mr. Mike Campbell of the U.S. Coast Guard Loran Support Unit for all of the technical assistance he has provided throughout this endeavor.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-Note-

The views expressed herein are those of the author and are not to be construed as official or reflecting the views of the Commandant, U.S. Coast Guard, of U.S. Department of Transportation.

## Questions and Answers

ED BUTTERLINE (Symmetricom): I have a question related to the future of LORAN. I hear a rumor that the Coast Guard has requested $100 million from Congress to perform deferred maintenance and extend the life of the system up to 2006 or 2008. But the last official words I have seen or heard is that the system is going to die in the year 2000. What is the future of the system as you now know it as we are sitting here right now?

LT. LEE PUTNAM (USCG): Unfortunately, I am the Public Relations Officer at NAVSAT. No, I have the answer to this question, and every time I give a talk, for some reason; I do not know why; 1996 Federal Radionavigation Plan stated that the Coast Guard will discontinue operation December 31st of the year 2000. That same year, Congress mandated that a study be conducted by the Department of Transportation on the cost and benefits of continuing LORAN beyond that time. That study was completed this spring by Booz-Allen and Hamilton, Incorporated, and was forwarded by the Secretary of Transportation to Congress.

The study recommended continuation of LORAN beyond 2015. The Commandant of the Coast Guard, the head of the FAA and some upper level management people in the department made a recommendation to the Secretary that LORAN be continued to 2008. The Coast Guard has gone forward with a budget request this year for recapitalization money for the year 2000.

One of the things the Coast Guard said was we have a system that is 25 years old and has not had significant recapitalization since it was established, and it is not going to make it past 2000. We still operate HP 5061s that you can not get tubes for anymore unless you get remanufactured ones, so there are obviously some things that have to be replaced. So because of that, we said we need $107 million over a five-year period to recapitalize the system if we are going to continue to operate beyond 2000. So there is a budget line item request of approximately 34 million for the year 2000. That is basically where we are at this point. That line item is under review and there has been no formal decision from the Secretary as to where we are going to go forward.

ED BUTTERLINE: My concern is that there was a flaw in the Booz-Allen and Hamilton study, that it did not consider a major piece of the national infrastructure as a user of LORAN. That oversight, I think, should be corrected and should have some effect, and what I am talking about is the use of LORAN as a timing source by the national telecommunications infrastructure. That is certainly a significant piece of the national infrastructure, and while it does not depend a hundred percent on LORAN, it does use it as a backup system. It was not reflected in the Booz-Allen and Hamilton study.

LT. LEE PUTNAM: I would agree with you that it is not adequately reflected in the study. I do not want to argue on behalf of Booz-Allen and Hamilton, but I do know that they did make an attempt to get input from that community. The attempt was met with one reply from a major telecommunications concern – let me retract that, it was met with two. One of the replies was withdrawn. I do not know the reason and I do not know how to answer your concern. But I do agree with you. The Coast Guard feels the same way, that we are part of the national infrastructure for dissemination of UTC and also for frequency. That was not reflected in the study very well.

DEMETRIOS MATSAKIS (USNO): For the honor of the USNO, I think I should correct something that you said. I do not think there was any trouble with our measurements taken on our LORAN calibration trip; I think the problem, the reason it was inconclusive, was due to unmeasurable propagation delays which could have been modeled with considerable theoretical effort that we had not gone through yet. Although it is certainly the case that if we ever do another calibration trip, we will go with even more equipment and do an even better job for you – which we are happy to provide.