LORAN-C DATA REDUCTION AT THE U.S. NAVAL OBSERVATORY

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Abstract

As part of its mission and in cooperation with the U.S. Coast Guard, the U.S. Naval Observatory (USNO) monitors and reports the timing of the LORAN-C chains. The procedures for monitoring and processing the reported values have evolved with advances in monitoring equipment, computer interfaces and PCs. This paper discusses the current standardized procedures used by USNO to sort the raw data according to GRI rate; to fit and smooth the data points; and, for chains remotely monitored, to tie the values to the USNO Master Clock. The results of these procedures are the LORAN time of transmission values, as referenced to UTC(USNO) for all LORAN chains. This information is available to users via USNO publications and the USNO Automated Data Service (ADS).

Introduction

On 1 June 1961, the U.S. Naval Observatory (USNO) began monitoring the LORAN-C signal of the East Coast chain transmitting from Carolina Beach, North Carolina **[1]**. The time difference values were taken manually at 14:00 Local Standard Time (LST) (this particular time was chosen in view of the diurnal shift of the signal). A few years later, time corrections were needed for the West Coast and other LORAN chains. USNO in Washington, DC, is located outside the groundwave coverage of these LORAN chains; therefore, a need to develop remote monitoring stations was created. This also meant that methods to tie the remote reference clock to the USNO Master Clock (MC) had to be developed. In the beginning, the readings were taken manually. A portable clock from the Observatory visited each remote monitoring site to determine the difference between the station reference clock and the USNO MC.

With the advent of microcomputers, many of the manual operations could be done automatically. This included the taking of readings, sending data to USNO for analysis, and adjustment of local time standard to USNO Master Clock. These automated monitoring systems require little or no human intervention except in the cases of equipment failure or the encountering of an error that cannot be predicted, e.g., data corruption by noise on the phone line.

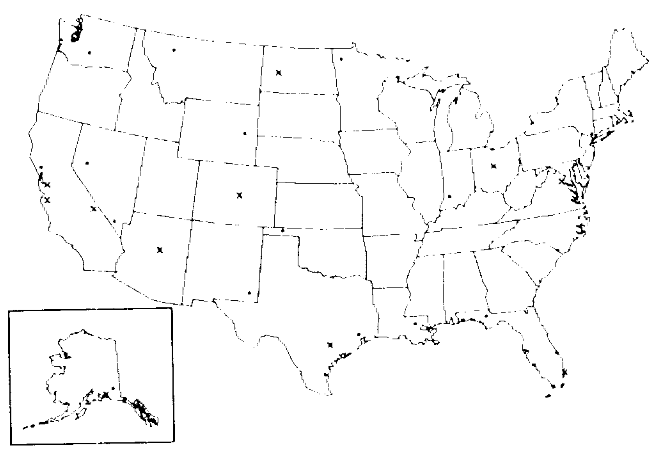

Figure 1 — Approximate location of LORAN transmitters (·) and USNO DASs (×) to monitor the LORAN timing signal.

Data Collection Methods

The LORAN Time-of-Arrival data (TOA), from which the Time-of-Emission (TOE) information found in the USNO Series 4 Publication is derived, are collected by microcomputer-controlled Data Acquisition Systems (DAS) located at USNO and throughout the United States.

USNO and most of these remote DAS units monitor both LORAN and GPS signals. The LORAN chains outside the U.S. are monitored and data analyses are performed using other methods not covered in this paper.

Each morning, HP1000 computers begin a scheduled sequence of events (see flowchart 1). Each of the remote DAS units receives a phone call from a computer. The LORAN and GPS data are downloaded into the HP1000 and the DAS starts collecting data again. Because of the amount of data collected at some locations, this data transfer can take several minutes to complete. The phone calls are made early in the morning because of the long data collection time slowing computer processes and the needs to have the completed results available by certain deadlines, to reduce telephone costs, and to obtain the highest data transmission quality possible. Once all the collectable DAS data are in the USNO HP1000 computers, it is transferred to a UNIX work station environment, where all data analysis is performed. The work station was chosen because it processes data more than 30 times faster then the HP1000. Its versatility allows for data collected in numerous ways to be centrally processed, and it provides an extra level of security. The software that is commercially available or is custom written at USNO allows the data, once they are entered, to remain in the same computer (albeit in different forms) until the final reports are created and sent out. The work station runs a single master set of data analysis programs rather than an individualized set for each DAS's data. This makes program maintenance and system operations considerably easier.

Data Analysis

The raw data are received from the HP1000 computers into the work station via inter-computer file transfers (USNO has DAS systems on two independently running HP1000 computers. This allows for increased reliability and system checks). Once the data are located in the work station's file system, a series of programs are executed by means of script files (similar to PC batch files). In many instances, one script file calls another, which in turn calls a third. By having the processes controlled by a series of script files, any segment or group of segments of the data reduction process can easily be reprocessed if necessary.

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--------------------
48520.8333333
99600.5
.02665509
--------------------
48520.8750000
89700.1
.07449299
--------------------
48520.9166667
89700.3
.01639081
--------------------
48520.9583333
99600.1
.06952863
###########
3   1991263235248   1991264000006   69    +2.80E-011   +186.516E-010   +15.4E-009   -15
12  1991264000306   1991264001300   100   +5.18E-012   +320.117E-010   +12.0E-010   -15
12  1991264001312   1991264002306   100   -5.58E-012   +314.471E-010   +12.4E-010   -15
12  1991264002318   1991264003312   100   +2.30E-011   +222.160E-010   +13.8E-010   -15
```

Figure 2-A sample of LORAN and GPS data as received at USNO from a DAS

The first program in the script files sorts and reformats the data. The data must be sorted because, at some locations, the LORAN data are in the same file as the GPS data (at other locations, the two data types are in separate files). Whether the data need to be segregated or not, this same program also reformats the data into a standardized form for the analysis programs and makes a copy for the history files (there is one master set of analysis programs requiring a standardized input data format).

These history files are used to reprocess data covering long periods of time. Once the LORAN and GPS data have been standardized in format and copies made for the record books, they can be reduced to more meaningful values.

The LORAN data-processing program analyzes all the data per block of time (usually 24 hours) during each pass through the input file. It will process the file as many times as needed to insure that all days with complete sets of data present are analyzed before terminating. As the data are read, the program sorts the data points into a large array according to the Group Repetition Interval (GRI) of the LORAN chains monitored at the particular site. The data points falling more than 750 nanoseconds away from the previous day's processed value are automatically disregarded. This filtering eliminates obviously bad values. After all data for the period in question have been entered into the array, all the GRI data points are linearly fit to a point of 01:00 local standard time. (The change from 14:00 LST to 01:00 LST was due to requirements of the U.S. Coast Guard for steering of the LORAN chains' TOE. It was also found that the data were much more reliable and consistent at this early morning hour.) While computing the linear fit, a sigma value of the fit is also calculated. One-and-a-half times this sigma value is then used as a filter for a second pass through the linear fit solution. This second result is then smoothed to remove the extreme effects from the environment and filed for later use. From previous research, it was found that no LORAN chain jumps more then 30 nanoseconds from one day to the next under normal circumstances. When a value does jump more than thirty nanoseconds from one day to the next, the filed value is the previous day's processed value plus half the jumped amount [2].

MJD TIME	8970-M	8970-X	9960_M	9960-Z
48500.250	-0.13	-0.15	-0.08	-0.11
48501.250	-0.15	-0.18	-0.13	-0.14
48502.250	-0.08	-0.10	-0.08	-0.11
48503.250	-0.04	-0.07	0.02	-0.01
48504.250	-0.04	-0.09	0.05	0.07
48505.250	-0.10	-0.14	0.02	0.05

Figure 3-Processed LORAN. A sample of LORAN data after linear fit processing for four LORAN stations.

Date MJD	USNO MC-GPS	Slope	RMS	N	DAS SC-GPS	Slope	RMS	N	USNO-DAS	Slope
48500.0	0.013	0.000	0.011	77	-0.004	-0.006	0.011	222	0.017	0.007
48501.0	0.023	0.012	0.009	74	0.010	0.012	0.012	223	0.014	0.000
48502.0	0.036	0.013	0.009	71	0.020	0.012	0.012	226	0.016	0.001
48503.0	0.041	0.004	0.010	75	0.027	0.010	0.010	224	0.013	0.001
48504.0	0.043	0.001	0.009	75	0.034	0.011	0.011	227	0.009	-0.007
48505.0	0.045	0.003	0.011	75	0.041	0.014	0.014	229	0.003	-0.004

Figure 4-A sample of GPS data after linear fit processing

The GPS data processing works much the same way as the LORAN data processing program. The data points from each monitoring site and USNO are entered into a large array. All data points outside a reasonable value are automatically disregarded. These data points are linearly fitted, two-times-sigma filtered, and linearly fitted a second time. These USNO versus monitoring site clock difference results are filed for later use. The present philosophy at USNO is to reduce all of the time values from the various satellites as though they were from one. This is referred to as the "melting pot" method of reduction. This linear fit method works well for a large number of data points or when only a very few data points are available from a consistent satellite from day to day.

In other cases, it is better to use the GPS common-view method. This method requires the monitoring site and USNO to be looking at the same satellite at exactly the same time in order to determine the reference clock time difference. As a result of the large number of variables present to perform the reduction of data, it is difficult to automate this process; therefore, it is only used at a few exceptional locations where automatic DAS units are impractical or unusable for technical reasons. In the case of remotely-monitored LORAN chains, the results from the LORAN data analysis are finally corrected to a value of USNO-MC minus the various chains by applying the GPS difference calculation. It is this corrected value from the remote DAS units and the values directly monitored at USNO that appear in the USNO Series 4 publication.

A separate program uses the reduced GPS values of the monitoring sites and the reported values for the various U.S. LORAN chains to calculate microstepper corrections. These corrections are applied to the remote station clocks and the LORAN transmitter units respectively. The monitoring site microstepper corrections keep each remote site's clock approximately set to the USNO MC. The LORAN microstepper settings assist the U.S. Coast Guard in meeting Public Law 100-223, which states that "each master transmitter shall be synchronized to within approximately 100 nanoseconds of universal time" [3]. The accompanying graphs are examples of how well this data analysis and microstepper corrections provided to the LORAN transmitting sites are keeping the LORAN TOE values within tolerance.

MJD TIME	*8970-M*	*8970-X*	*9960-M*	*9960-Z*
48500.250	*-0.07*	*-0.09*	*-0.02*	*-0.05*
48501.250	*-0.09*	*-0.12*	*-0.07*	*-0.08*
48502.250	*-0.02*	*-0.04*	*-0.02*	*-0.05*
48503.250	*0.02*	*-0.01*	*0.08*	*0.05*
48504.250	*0.02*	*-0.03*	*0.11*	*0.13*
48505.250	*-0.04*	*-0.08*	*0.08*	*0.11*

Figure 5-Results. A sample of the processed LORAN value after correction of station clock via GPS for four LORAN stations.

Summary

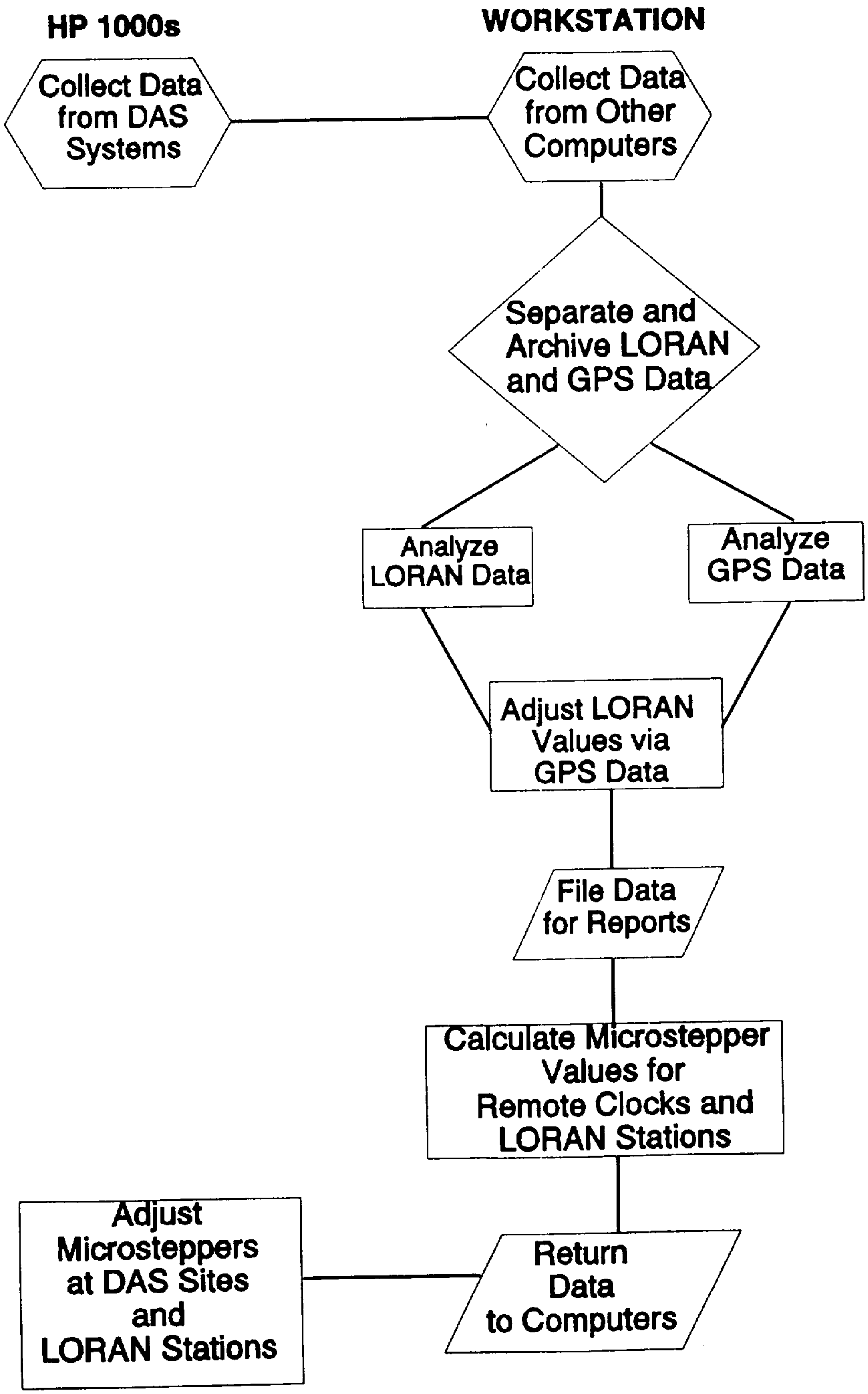
By means of automated Data Acquisition Systems and time-scheduled data analysis programs, the U.S. Naval Observatory is disseminating UTC time via LORAN-C transmissions to a greater accuracy then ever before. USNO is continuing its efforts in researching new analytical methods. It will also be investigating various methods by which users can increase the accuracy of their timekeeping relative to UTC time via LORAN timing signals.

References

1) Charron, L. G., "*Evaluation of LORAN-C Timing Techniques*", Proceedings of Wild Goose Association Meeting, October 1983, Washington, DC.

2) Miranian, M. (USNO), private communication.

3) Vogt, G. (USCG), private communication, 5 December 1990.



Flowchart 1-Flow diagram of LORAN and GPS data processing. The data for reports are found in the USNO Series 4 publication.

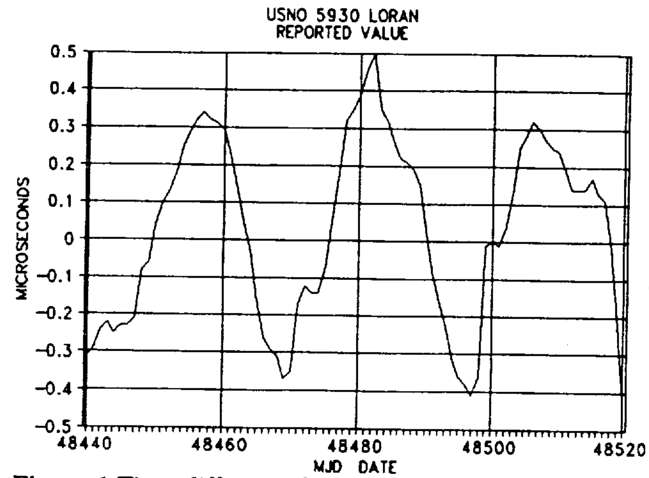


Figure 6-Time difference between the USNO Master Clock and the 5930 LORAN Chain.

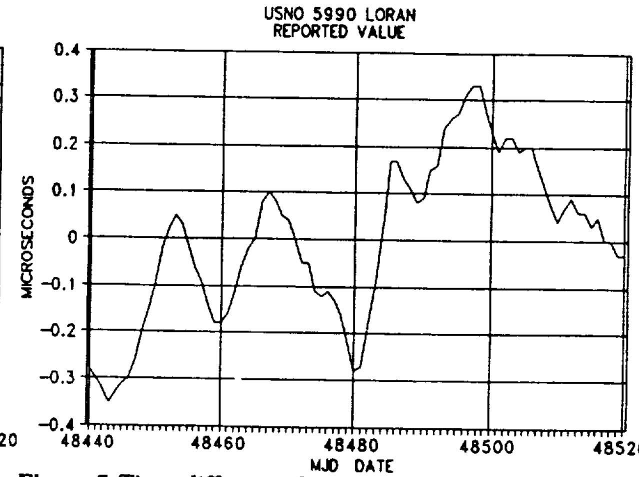


Figure 7-Time difference between the USNO Master Clock and the 5990 LORAN Chain.

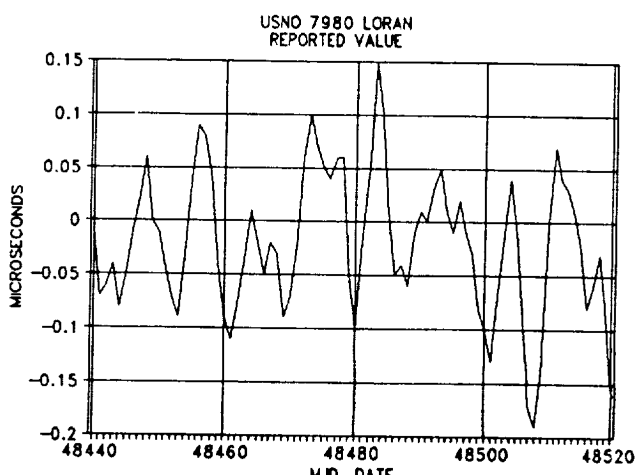


Figure 8-Time difference between the USNO Master Clock and the 7980 LORAN chain.

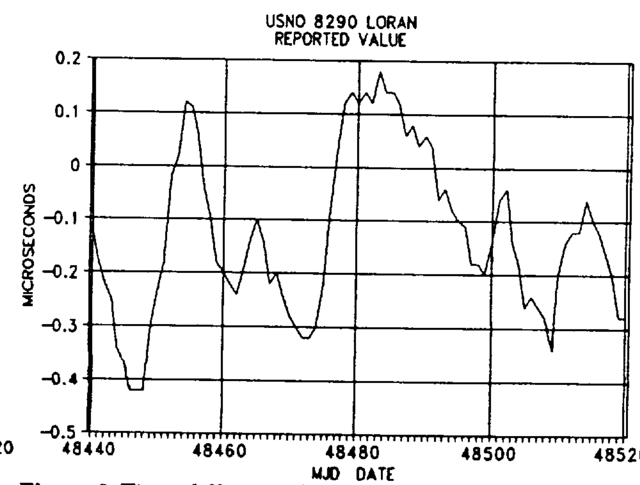


Figure 9-Time difference between the USNO Master Clock and the 8290 LORAN Chain.

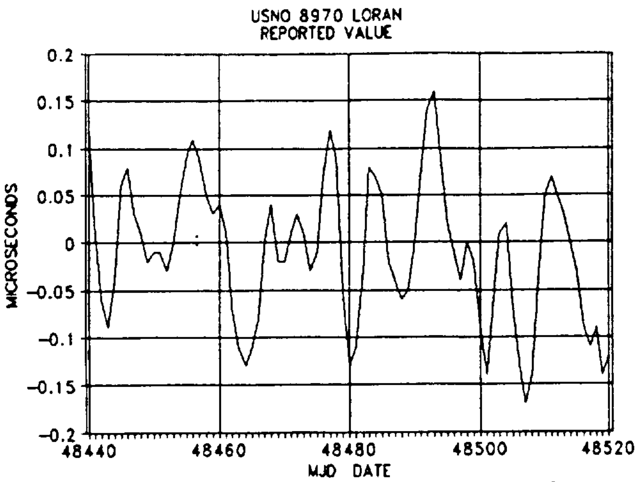


Figure 10-Time difference between the USNO Master Clock and the 8970 LORAN Chain.

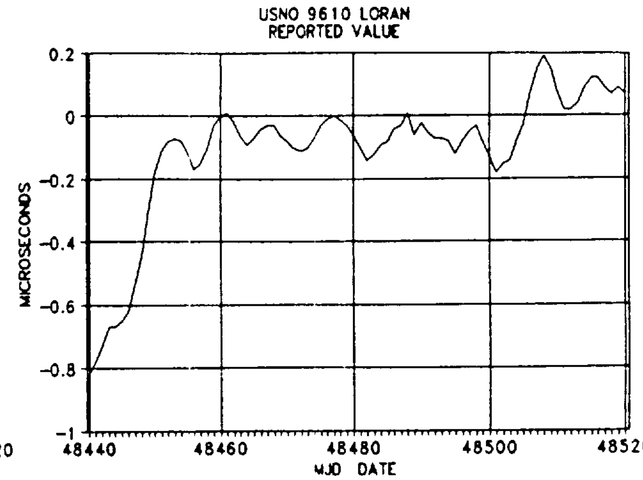


Figure 11-Time difference between the USNO Master Clock and the 9610 LORAN Chain. Note: USNO began providing steer corrections for 9610 on MJD 48440.

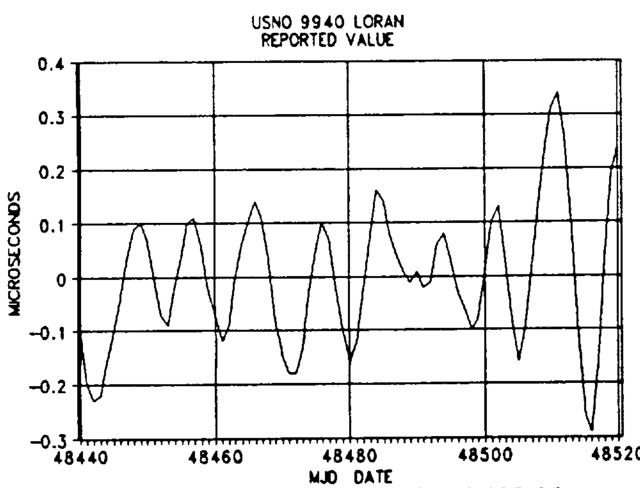


Figure 12-Time difference between the USNO Master Clock and the 9940 LORAN chain.

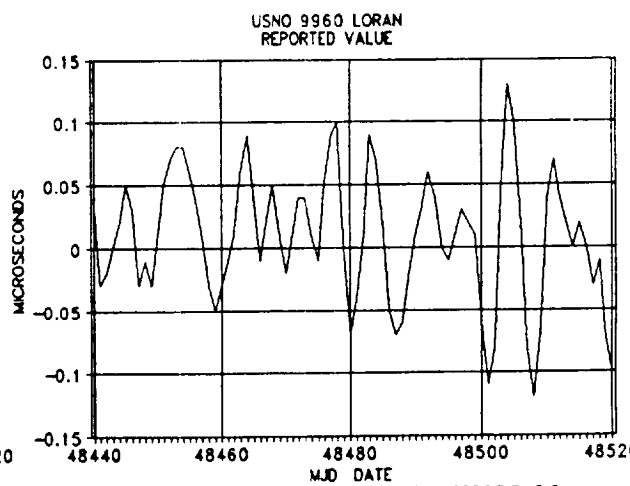


Figure 13-Time difference between the USNO Master Clock and the 9960 LORAN chain.

QUESTIONS AND ANSWERS

David Allan, NIST: Some work at NBS showed that you can look at the index of refraction as a ground wave, the gradient. One might be able to get some nominal weather data and do some modeling to see why these delay variations come, due to these storms and fronts, etc., and account for some of the variations that are causing you these tracking problems.

Mr. Chadsey: One of the things that we are looking at is the USNO is working on a project with the Coast Guard at the 9960 transmitting site at Seneca. We will be doing two-way time transfer with that transmitting site. Their clock will be set precisely to USNO, with a very small error. We will then monitor that *versus* received values, and plot that *versus* the various weather conditions that we can monitor, such as temperature, humidity, barometric pressure, etc. in order to try to model some of these effects. This will the first time that we can do it on a fairly accurate basis.

Mr. Allan: What I meant to say was that they said that the strongest effect was gradient, rather than the temperature itself. You might keep that in mind as work on the meddling.

Mr. Chadsey: That is one of the things that will have to come into this. As we do the weather plots, we will have to get weather, not only from the local receiver and transmitter sites, but also from points along the way and plot out the various lines.